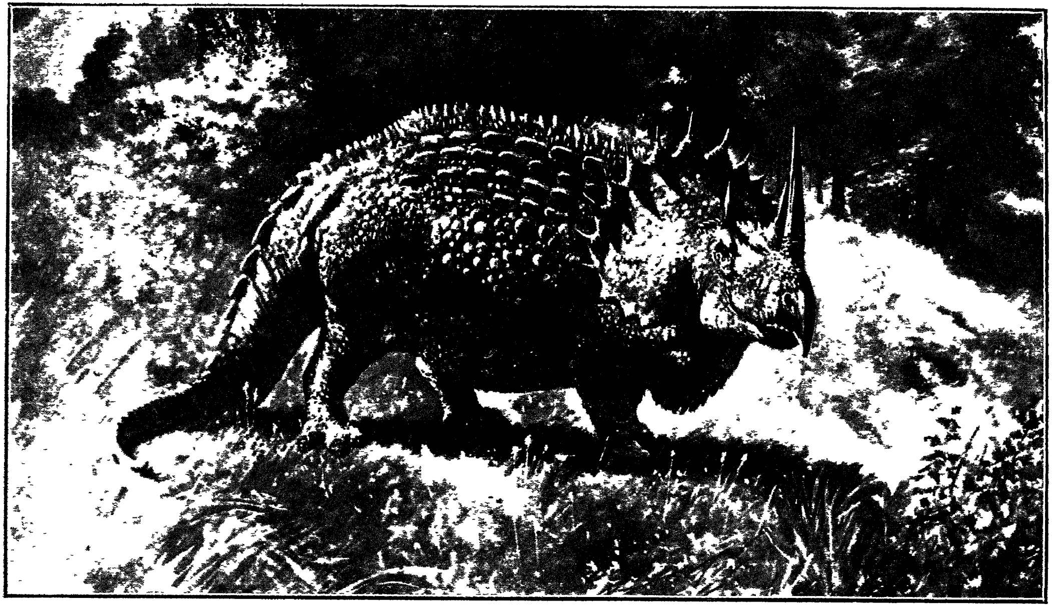
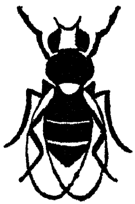


A monster of the past: *Monoclonius*, a horned dinosaur of the Upper Cretaceous. (Original painted by Charles R. Knight under the direction of Henry Fairfield Osborn; photograph from the American Museum of Natural History.)

THE
INSECT MENACE

By L. O. HOWARD



ILLUSTRATED

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PREFACE

IT HAS seemed to me that there is room for a book on insects quite unlike any of the numerous books that have been written about them. Every one knows Fabre's writings, and many people have read Maeterlinck on the honey-bee and on the termites, as well as Wheeler's remarkable study of the ants. The special students are familiar with Comstock's well-known Manual and the great works of the Englishman Imms and the Australian Tillyard. Then, too, there are numerous special works on economic entomology, destined for the farmer and the fruit-grower and for the students in the colleges of agriculture—such as those by Fernald, Herrick, and Metcalf and Flint, for example, to mention some of the more recent ones.

But the warfare against insects is becoming so important that it is attracting the attention of a large number of people, and the reasons for this should be known generally. Therefore I have tried to epitomize in a small volume what should be known by every one. It is not a study of the marvels of insect life; it is not really a very scientific book; nor is it a manual for agricultural students or for farmers or fruit-growers. It is intended for the thoughtful general public.

Its object is to arouse such a public to an appreciation of a very real menace to humanity. I began to study insects more than sixty years ago. I have worked against them officially for over half a century. The importance of their study has been growing on me all these years, and during the past ten or more I have seen that the insect menace is increasing under present conditions, and increasing rapidly. Every one should realize the situation, and this little volume is one of many efforts to bring about the realization.

INTRODUCTION

EVER since the days of Malthus there have been broad students of the world population, of its progress and its future, and the prophets of evil things to come have predominated among these writers. For example, in 1898, Sir William Crookes, basing his argument largely upon the approaching exhaustion of our supply of fixed nitrogen, predicted so rapidly decreasing a wheat supply as to bring about disaster in the early third of the present century. It is true that ten years later Professor E. L. Nichols made a much more hopeful statement concerning the nitrogen supply, since the air was already being used as a source. Nevertheless, disconcerting prophecies continued to be made.

In 1922, Raymond Pearl, for example, predicted a saturation point in the United States, under the standards existing at that time, of a population of approximately two hundred millions. And then, in 1923, E. M. East, of Harvard, published his startling book "Mankind at the Crossroads," in which he stated that the facts of population growth and the facts of agricultural economics point to the definite conclusion "that the world confronts the fulfilment of the Malthusian prediction here and now."

After elaborate and convincing argument Professor East expressed himself as inclined to agree with Pearl's estimate regarding the United States. He showed that by our present standards of farming the country will support only one hundred and sixty-six millions of people and that to feed a hypothetical doubling of such a population it will be necessary to double the present production on every acre of available land and to keep the production continuously on this basis. He goes on to show in various ways that this will be virtually impossible, and among other significant facts he points out that in 1915, for example, the wheat crop reached a thousand million bushels, but that in 1916 the chinch-bugs and the weather combined to drop it to six hundred and thirty-six million bushels. The book winds up with a strong plea for birth-control.

Enormously impressed by East's book, and seeing the vital relation between the facts and arguments and the broad subject of insect-control, in 1924, in an address as Chairman of the Pan-Pacific Food Conservation Conference at Honolulu I advanced the thought that there were three things upon which the world should concentrate: (1) Invention of new foods or the discovery of methods by which the supply of foods at present in use could be enormously increased and very rapidly produced; (2) birth-control, and (3) stoppage of waste—the greatest of all wastes, in my opinion, being the feeding of increasing hordes of insect crop-enemies. Since that time I have said virtually the same thing over and over again in articles and in addresses.

The work in the different branches of science as applied to agriculture has been going on steadily, with admirable results. Nevertheless, warnings and prophecies continued to be published in one form or another. For example, in 1928, Sir George H. Knibbs, Chief Statistician to the Australian Commonwealth Government, looked ahead for two hundred years and emphasized the necessity for the most serious consideration of food supply and increasing population. The same year Dr. von Penck, of the University of Berlin, in a series of lectures given at the University of California, expressed himself as of the opinion that a crisis was not far distant, but he placed it at the somewhat remote period of three hundred years hence.

With all this in mind, I was rather surprised at the wholly optimistic attitude shown in two notable addresses made at the convocation at Rutgers College on October 9, 1930, by Sir John Russell, head of the Rothamsted Experiment Station, and by Dr. A. F. Woods, Director of

Scientific Work of the United States Department of Agriculture. The speakers scouted the older predictions and showed that, owing to the work of the scientific men in all branches relating to agriculture, the problems of future food have been virtually solved. This would seem at first glance to take much of the wind out of my sails, but in reality it does not do so. Apparently in the minds of these men it has been taken for granted that the entomologists have solved or will solve the insect-waste problem. But that is going too far. We have not solved the problem. It is one of increasing complexity. It is true that in many instances we have pointed out what might be done, but in altogether too many cases —either because of ultraconservatism on the part of the agricultural public or for minor economic reasons that have overshadowed in the minds of the growers the broader features involved—our conclusions have not been heeded.

Of course it is altogether likely that the optimism of Sir John and of Dr. Woods is perfectly justified. The former has been a great student of soils and of general agriculture, and the latter, originally a plant pathologist and later an experiment-station director and a university president, has been for some years the director of all of the scientific work of the United States Department of Agriculture. Thus both men are eminently qualified to take a broad and comprehensive view. But are they warranted in their apparent reliance on the work of the entomologists? Do they fully realize the insect danger?

To the latter question I am inclined to answer negatively. To the former I would answer affirmatively could I be assured that the number of workers in entomology will be decidedly increased, that they will be given the strong cooperation of workers in several other branches of science, and *that their advice will be followed by the actual producers of food.*

I believe I first began to write very seriously on this question in 1920, when a large part of my address as retiring President of the American Association for the Advancement of Science was taken up with some of these thoughts. The idea was grasped at once by a number of writers, and since 1920 numerous magazine and newspaper articles have been published that have emphasized the insect menace. One of the most effective and pessimistic of those articles was published almost immediately by Mr. Peter McArthur, a well-known Canadian writer. (The address above referred to, by the way, was delivered at Toronto, Ontario.) Mr. McArthur brought out a very strong article in a Canadian journal. His closing sentences are worth quoting:

Best of all, if we could be made to realize our danger, we would have something else to think about than national honor, national aggrandizement and national glory. Civilization would be saved if we could once get the minds of men turned from their selfishness and aroused to the need of self-preservation. But I am afraid that the bug-fight cannot be given the pride, pomp and circumstance of human war. We could not march to it with flags flying and bands playing. And I am afraid that there would be no chance for the frenzied profiteering that is so stimulating to patriotism. I am afraid that the outlook is dark and that the insects will win.

A few years later, in 1926, the "Journal of Agriculture" of New Zealand declared:

It is not too much to say that the margin between sufficiency and starvation for the needs of the increasing population of the world during the next fifty years will in a large measure depend upon the success or failure of the work of trained entomologists.

This was, of course, long before the optimistic conclusions voiced by Sir John Russell and Dr. Woods were reached. Despite all that has been written, however, I have thought it wise to bring most of the arguments together and to describe as well as possible the situation to-day.

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Chapter I

HOW LONG HAVE INSECTS EXISTED ON THE EARTH?

ONLY the geologists, paleontologists, and astronomers are accustomed to think in terms of millions of years. Paleontologists speak habitually of eras and periods and epochs, calling them by long Latin names; and when you are talking to a paleontologist you are speaking with a man who apparently has little respect for the human species as a subject of scientific study. The reason, to him, is that the human species appeared so late in the history of the world. And I am mentioning the fact as indicative of the slight importance, from this point of view at least, of the human species when we compare it with other forms living on our planet. The paleontologist tells us of the first appearance of insects in what he calls the late Paleozoic, which was probably more than forty millions of years ago; and even then they were so well developed that they must have originated at a much earlier period.

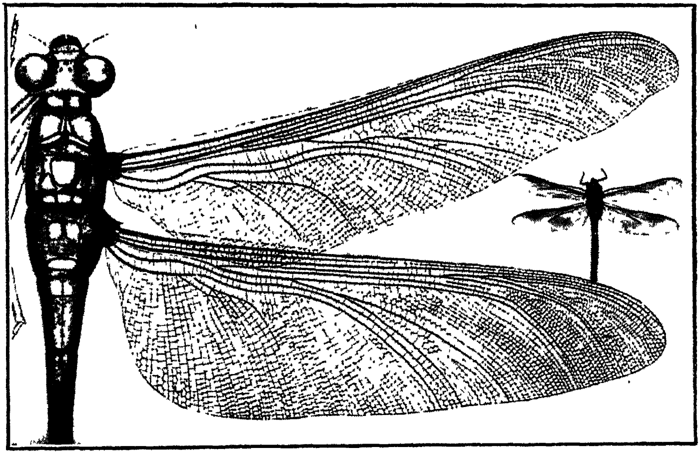
Long after the insects, came the land vertebrates, the flying reptiles, the birds, the flowering plants, the extinction of the great reptiles, the vanishing of the archaic mammals, the rise of the higher mammals and their culmination, before man appeared; and the primitive man did not make his appearance until probably half a million years ago—possibly a little longer.

Here, you see, is a history that shows that the insects came into the world, became highly diversified, and continued to multiply and to evolve during ages upon ages of changing conditions, adapting themselves to every change and becoming more and more perfectly fitted for continued existence down to the present time.

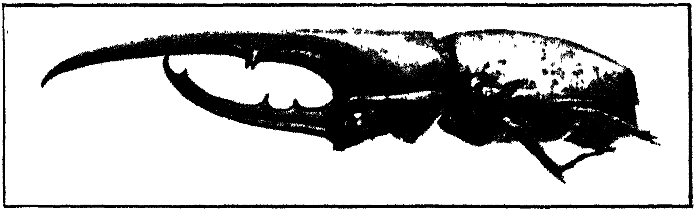
But in treating of subjects like this, we must not compare time in terms of human chronology; that is, in years. We must put it into terms of generations. A few years ago I pointed out that the cotton boll-weevil has been in the United States approximately thirty-six years and that during that time it has apparently physiologically become a greatly changed species. That period covers only two generations of human beings, but it covers two hundred and sixteen generations of the weevil.

Let us look at the larger matter in the same way and in the same terms:

Aleš Hrdlička told me a year ago that the human species is known to have been in existence



An Upper Carboniferous dragon-fly (*Meganeura moneyi*) with one of the largest modern dragon-flies (*Epineura heros*) inserted between its wings. Both are reduced to approximately two fifths natural size. (The figure of the ancient form is from Tillyard. The recent figure is from a photograph in place by J. G. Pratt.)

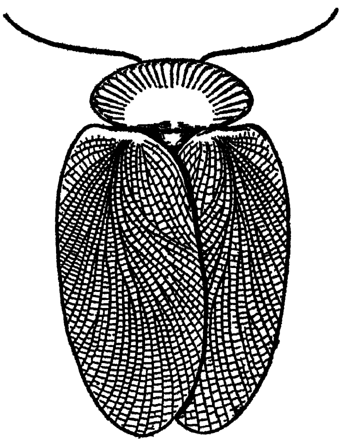


The Hercules beetle of tropical America (*Dynastes hercules*), much better armored than any of the dinosaurs, and much better fitted for existence on the earth. (After Schwarz.)

hardly more than 400,000 years. It is true that later discoveries seem to lengthen this period, but for the purpose of argument let us call it 400,000 years. In that period, allowing approximately 16 years for a generation (it is more nearly 25 nowadays), we have in the 400,000 years, 24,000 generations of human beings. Now, taking an average of 8 generations a year for insects, we find that in the same 400,000 years there have been 3,200,000 generations of insects, and in the 40,000,000 years that the insects have been upon the earth there must have been in the neighborhood of 300,000,000 generations. Thus, as I figure it, insects have had 12,500 times the chance that man has had to evolve a persistent type. And even this is not all, since undoubtedly insects have existed very much longer than 40,000,000 years.

Man, then, is a new-comer. He may be a fugitive inhabitant of the world, speaking in geological terms, but nothing in the whole range of biological and paleontological study shows anything to equal the insects in their persistence and in their possession of characteristics which would seem to assure their persistence even if such an experiment of Nature's as the human species should be found eventually to be an unfortunate and unsuccessful one.

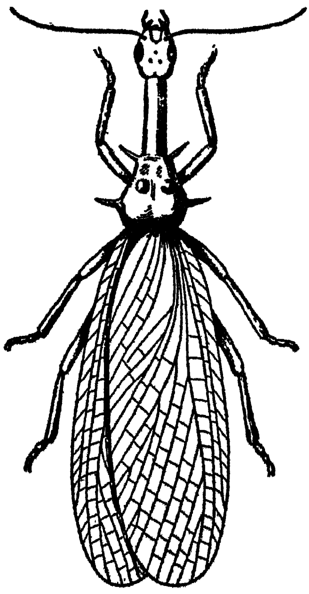
The earliest insects that we know were present with vast forests of non-flowering plants. Some of them were very large, having a wing-spread of more than two feet, and such forms lasted for a long time. These forms died out; and then the cockroach type came in, and, judging from the remains, cockroaches nearly overran everything. Ages later,



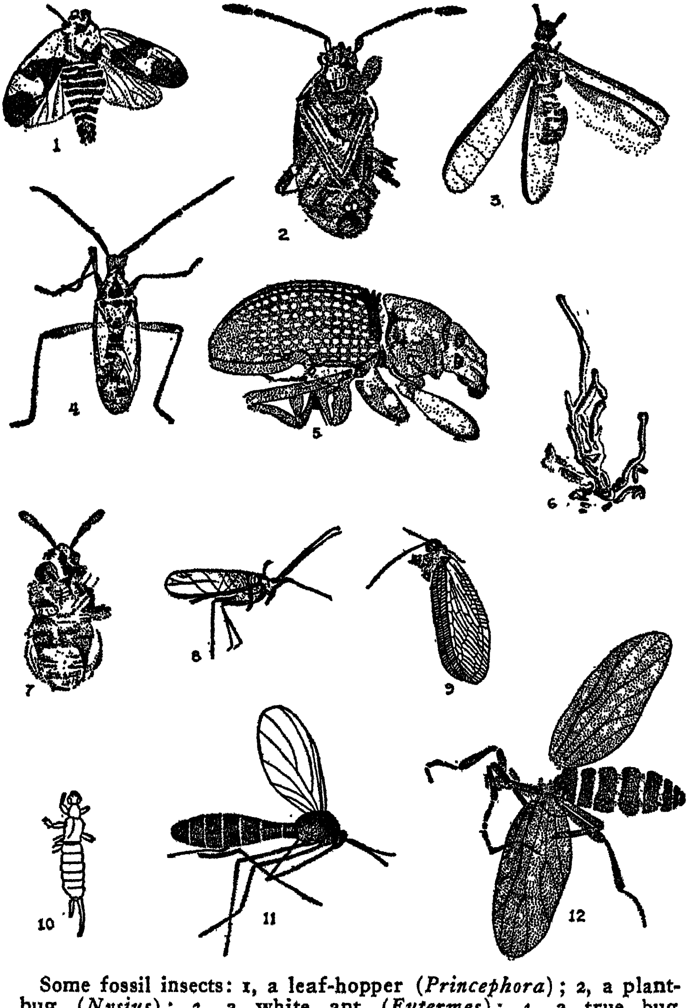
A cockroach from the Upper Carboniferous of France—reconstructed. (After Schroeder.)

with the cooling of the climate, countless smaller insects developed.

So it seems as though the insects were quite the most permanent and persistent type that life has evolved. And even if we agree with Hiram Maxim in one of his



An early ancestor of the grasshopper—*Gararus Danielsi*—reconstructed. (After Schroeder.)



Some fossil insects: 1, a leaf-hopper (*Princephora*); 2, a plant-bug (*Nysius*); 3, a white ant (*Eutermes*); 4, a true bug (*Closterocoris*); 5, a snout-beetle (*Otiorhynchus*); 6, beetle burrows in a fossil twig; 7, a true bug (*Procarphius*); 8, a plant-louse (*Tephraphis*); 9, a lace-wing (*Osmylus*); 10, an earwig (*Labiduromma*); 11, a midge (*Sackenia*); 12, a fossil fly (*Plecia*). (All redrawn from Scudder.)

guesses when he was considering the infinitude of space and time—that worlds like ours have existed many times and that an evolution of life like this on our globe may have occurred again and again on other planets—for the consideration of our present existence and of our relation to the forms of life that coëxist with us it is not too much to assume that insects will be here when we are gone! I am inclined to think, as Maeterlinck does, that they are our rivals here on earth and perhaps our successors; only I would leave out the "perhaps" and accept the prophecy of Dr. W. J. Holland that the last living thing on the globe will be some active insect sitting on a dead lichen which will represent the last of the life of the plants.

All this is decidedly dismal. The human species has not been here long enough to be half tried. It is half a million years since Pithecanthropus and his ancestors walked the jungles of Java, and what is even a million years in an experiment of Nature's! It is a far cry from Pithecanthropus to, say, Theodore Roosevelt; but if there is no absolutely cataclysmal happening in the next million years, we may expect a type of human beings as far superior to Theodore Roosevelt as he was to Pithecanthropus! That is the way the law of evolution works.

But there may come a cataclysm, in which case the human species may be wiped out, together with a lot of other higher animals and with flowering plants, making it necessary for that same old painstaking, long-suffering Mother Nature to begin to evolve something to take their places. But it is safe to predict that most of the insects, or such of them as are not dependent upon the crops carefully raised for them by human beings, or such of them as are not dependent upon flowers, will survive the conditions which have destroyed us and the others. Illustratively, Tillyard has found in New Zealand a primitive caterpillar feeding on a liverwort, a type antedating the flowering plants, and this insect type appears to have remained unchanged for millions of years.

What is a cataclysm or two to the insect class? Extending far back into the Paleozoic age, the insects have passed through cataclysm after cataclysm; and when they are subdued it will be safe for some possible historian in Mars to say, "That is the end of that world."

This line of thought, however, is rather futile, and it is set down simply as indicating in a bold way the character of the rivals which humanity must surely hold in check if it is going to make a big success as a species. Of course we are inordinately egotistic. Many of us believe that the world was created for us and that everything on the earth is intended in some way or another for our use. But the truth of the matter is that Nature is quite as much interested in the insects as she is in man, and in permitting the evolution of their remarkable structure and their extraordinary instincts she has allowed them to gain a very high rank in life. With us she seems to be trying an entirely different experiment. She has given us quite a different body structure; she has not restricted our tools to the physical appendages of our own bodies, as she has with the insects, but has so endowed us that we can make tools for ourselves and, what is still more to the purpose, so that we can make tools to make other tools; she has given us language, fire, and above all has permitted instinct to blossom out into intelligence by the use of which we can study the records of the past and can profit by the achievements and mistakes of our ancestors and so work toward a future of almost limitless possibilities.

I have a fanciful thought. I can imagine Nature sitting back with a complacent smile and saying to herself: "Now I am going to witness an interesting spectacle. This last thing that I have produced (he calls himself man) I have given the chance to control most things on earth. Let us see what he will do with my especial pets, the insects, which I have developed and perfected for so many ages. The humans are going to have a very hard fight to hold their own, and I am not quite sure whether they are going to win. In any event the struggle will be an interesting one to watch."

But we must say something more about the antiquity of the insect class, in order to emphasize the contrast we are drawing. The best students of fossil insects—and there are not very many of them—are inclined to frown down the contention that the remains of delicate wingless insects have been found in the so-called Devonian rocks. The only remains that they will acknowledge as those of true insects are winged species, of high development and diversification. In fact, only winged insects appear to have been preserved as fossils. It seems that the chitin of the insect skeleton, although very resistant to acids and alkalis, dissolves slowly in water, so that the actual substance of the skeleton is rarely preserved in the rocks. Generally it has become changed through chemical action, and is often completely dissolved away, leaving only an impression of the insect on the rock in which it had become inclosed. Most insect fossils are composed of isolated wings only.

What is termed by paleontologists the late Paleozoic is also known as the Carboniferous age, in which there were great forests of plants that are now coal. And in the Upper Carboniferous rocks, as Tillyard puts it, "we suddenly come upon the remains of a wild riot of teeming insect life." It appears as though insects might well be considered to have been then at the maximum of their development, especially as to size. It was at that time that some of them had a wing-spread of more than two feet. The period has been called the giant age of insects. It is perfectly obvious that we must place the origin of insects at a much earlier period. It is not necessary to theorize regarding their line of descent, but there cannot be the faintest doubt that millions of years must have transpired in the evolution of the insect world as it existed in the Upper Carboniferous, and even that was forty million years or more ago. The giant insects lasted for a long time, but finally died out.

It is astonishing what comparatively slight changes have taken place with certain groups of insects through millions of years. Cockroaches of those old days were extremely like some of the cockroaches of the present. And we may say the same of other forms. Take mosquitoes, for example. There is a geological formation known as the Oligocene which occurred in the early Tertiary period, a time just after the vanishing of the Archaic mammals, a time of the great development of herbaceous plants. Now, in rocks of that period, from the Isle of Wight, have been found impressions of mosquitoes. The genera appear to be inseparable from those living now, and the indications supplied by some of the species suggest that in those days there was a fauna on the Isle of Wight not unlike that of the Ethiopian and Oriental faunas of the present time. Mosquitoes of the modern genus Culex and one of the modern genus Tæniorhynchus have been found, and several of the modern genus Aëdes. It is interesting to note, however, that no members of the malaria-carrying genus Anopheles have been found.

Mr. F. A. Lucas in his "Animals of the Past" has a chapter, toward the end of the book, entitled "Why Do Animals Become Extinct?" The plain answer as to the cockroach and as to the mosquito is: They do not become extinct!

An author in the English journal "Nature," in reviewing a monograph of the fossil insects of the British coal-measures, referring to this persistency of type extending through the ages, makes several significant statements. He says, for example, that the cockroaches since the Carboniferous period "have shown themselves proof against all evolution. They are *permanent* organic types . . ." Later he says, "Thus paleontology rehabilitates the cockroaches. They are far from meriting our scorn, for they are of aristocratic descent and the most conservative of all creatures."

About 11,500 species of fossil insects are known, and of these only approximately one fifth belong to orders or families that do not exist to-day. It must be remembered that these insects have been studied mainly from wing impressions and that complete insects were not found until the amber fossils of the Miocene age.

The so-called Baltic amber is the fossil resin of pines that grew during Lower Oligocene Tertiary times in northern Europe. Some of it contains insects fossilized in nearly perfect condition, which must have lived millions of years ago. Dr. W. M. Wheeler's study of the ants discovered in this amber showed conclusively that ants have not since undergone any important structural modifications, and that at that early period they had developed all of their different castes just as we see them now. Dr. Wheeler tells us that their larvæ and pupæ were identical with those of to-day, and that they apparently attended plant-lice, kept guest beetles in their nests, and had parasitic mites attached to their legs, in the same way as in our living species. He found that at least six of the seven existing subfamilies and many of the existing genera were fully established. Furthermore, he makes the astonishing statement that some of the species in the amber are virtually indistinguishable from those now living in northern Europe and North America.

If any geologist has taken the trouble to read what I have written so far in this chapter, and particularly if any up-to-date physicist has done so, undoubtedly he will say that I have been a little weak in my statements regarding the estimates of the time for the different geological periods or epochs. This is undoubtedly true. I am familiar with the estimates of time periods made by physicists on the basis of the rate of decomposition of radium, and especially the estimate by Strutt that the Upper Carboniferous (in which the gigantic insects were so numerous) existed 146,000,000 years ago. Of course I must mention this, but the case as we are trying to show it is quite strong enough with the older estimates of the geologists who thought that the sum of 40,000,000 was large enough!

If the reader will examine carefully the diagram on the next page, I am sure he will be edified and that he will appreciate the present rank of insects in the animal kingdom better than he could after reading many lines. It shows beautifully and in a condensed form the groups of animals that have disappeared in past ages, the groups that are represented to-day, and the

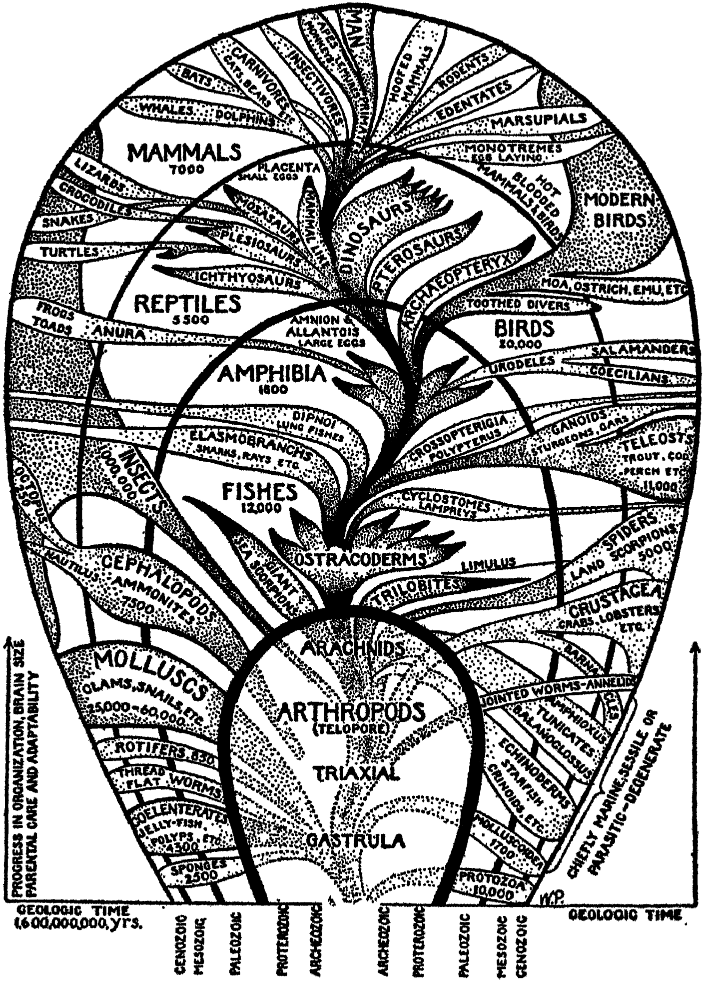
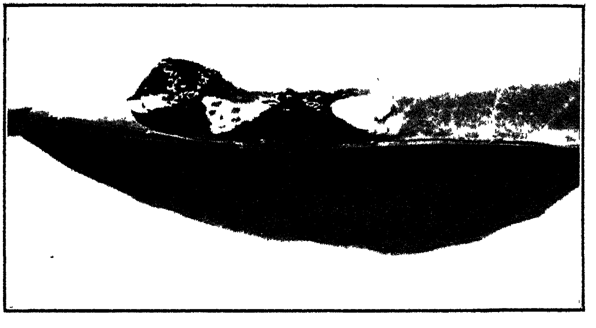


Diagram illustrating the rise and decline of all the great classes of animal life. Note that insects have very rapidly increased and that virtually every other group has declined with the exception of man. (From William Patten.)

A wood-boring beetle—*Goes trigrinus*—in center of picture, sitting on bark of a white oak and so closely resembling the bark as to be difficult to distinguish. (Natural size. Photographed by H. B. Kirk.)



Larva of the large swallow-tail butterfly of the Florida orange groves—*Papilio cresphontes*. It resembles a bird-dropping. (After Hubbard.)

progress of the latter. At the extreme top of the diagram, man is shown on his expanding path, but when we look at the insects we notice that they have expanded in the most extraordinary way and are still expanding immensely beyond any other group of animals. In fact, all the other groups except man and the modern birds are retrograding, and numerous groups have become extinct, some gradually, some rapidly, and some (the Dinosaurs—see frontispiece) abruptly. Another diagram could be constructed giving an extended marginal space to the insects, but it will be unnecessary. The one here given is taken from a remarkable paper by Professor William Patten of Dartmouth College, entitled "The Ways of Man, Apes and Fishes," published in the "Scientific Monthly" of October, 1930.

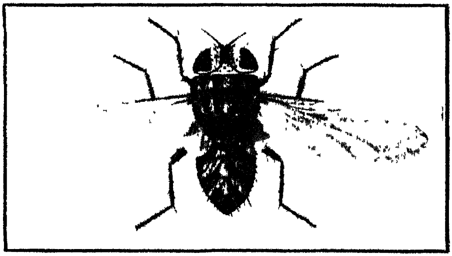
Chapter II

WHY THE INSECT TYPE HAS PERSISTED

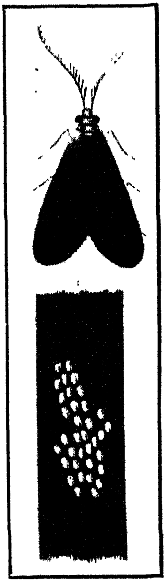
WHEN we study insects carefully, there become evident innumerable reasons for the continued prosperity of the type. I have been greatly impressed by a paper entitled "The Fundamental Factor of Insect Evolution," by S. S. Chetverikov, of which the translation by J. Kotinsky was published in the Smithsonian Annual Report for 1918. Chetverikov believed that in the evolution of vertebrates the primitive forms were small, and that these animals worked toward self-preservation by the accumulation of strength and bulk, the forms living on vegetation increasing in bulk as a protection against the smaller flesh-feeders, and the flesh-feeders increasing in strength in order to overpower the larger plant-feeders. This resulted in gigantic and highly specialized forms. With the changing of conditions, these enormous and specialized animals were not able to adapt themselves, and died out.

With insects, however, the shortness of the

Prospaltella berlesei laying its egg in the mulberry scale, *Diaspis lanata.* (After Berlese.)



Ptychomyia remota, the successful parasite of the Levuana caterpillar. (After Tothill *et al.*)



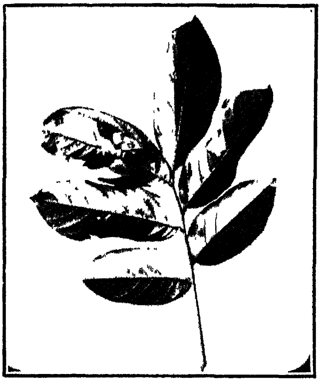
The adult of the Levuana caterpillar, and its eggs. (After Tothill, *et al.*)

life-cycle and the quick cessation of growth of the individual prevented the development of great size, and consequently the evolution of insects proceeded in quite the opposite way. Insects seem to have been growing smaller and smaller and more and more highly specialized. Their external skeleton has been an important source of help in their evolution. The Russian author works out as an engineering problem the superior strength of the limb of an insect, with the skeleton outside, over the limb of a vertebrate with the skeleton inside, showing that the vertebrate limb, other things being equal, is three times weaker than the insect limb. "There is a decided and tremendous advantage in the insect skeleton." Moreover, the ectoskeleton affords an endless opportunity for the development of external characters, giving rise to the extraordinary variety of insects as they exist to-day, which of course have developed by means of an enormously long and slow evolution.

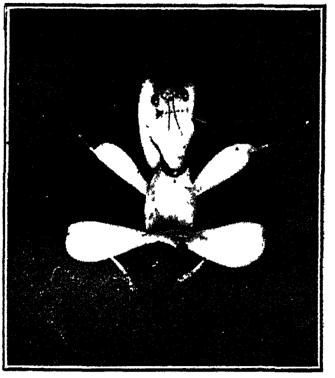
He sums up by stating that the fundamental cause of the opposite directions of the paths of evolution of vertebrates and insects is the presence with the insects of the outer skeleton by means of which they have been able continuously to diminish the size of the body and to make an entirely independent place for themselves among other land animals, "to increase in an endless variation of forms and thereby to acquire a tremendous importance in the general economy of nature. Thus their insignificance became their power."

Apparently, then, insects have been growing smaller and smaller, although very gradually, since in their minute size has come a large measure of their ability to survive. This small size also is an important element in their power to conceal themselves from their enemies. But to hide by penetrating a tiny crevice is by no means the only way of hiding. There has developed in the course of ages of evolution a power of concealment on the part of insects which depends upon a multitude of factors and which has brought them into such close resemblance to their general environment and to specific features of their environment as to conceal them in a marvelous manner.

The subject of protective coloration has been wonderfully developed by the writings of many naturalists of recent years. The late Abbott H. Thayer, who was both an artist and a naturalist, showed many striking things about the protective coloration of birds and higher animals, and a number of the principles which he evolved from his studies were used successfully



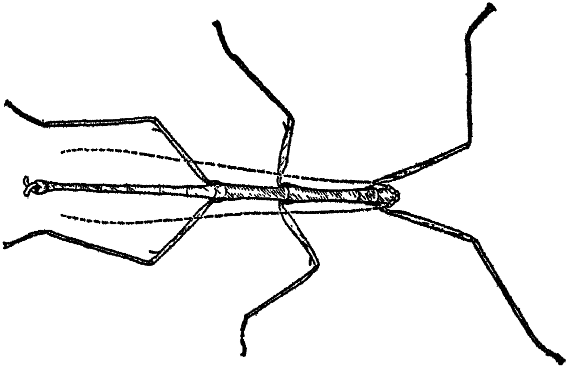
A remarkable leaf insect from Java. (Photograph from David Fairchild.)



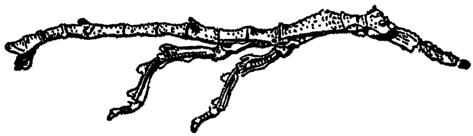
A flower mantid from Java. (Photograph from David Fairchild.)

A tropical mantid colored and marked to resemble the peculiar vegetation haunted by it.

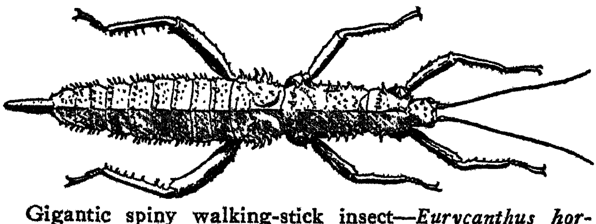
Measuring-worms—larvæ of Geomitrid moths—in attitude and appearance resembling twigs.



The common United States walking-stick insect—*Diapheromera femorata*. Length, 2½ inches. (From Snodgrass. Courtesy U. S. Dept. Agriculture.)

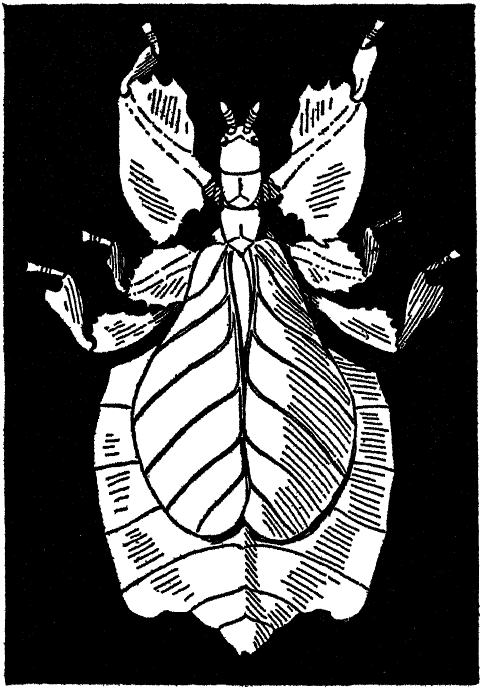


A tropical walking-stick insect.



Gigantic spiny walking-stick insect—*Eurycanthus horrida*—from New Guinea. Length, 5½ inches. (From Snodgrass. Courtesy U. S. Dept. Agriculture.)

in camouflaging ships and land structures and bodies of troops in the World War.



Tropical leaf insect—*Pulchriphyllum pulchrifolium*. Length 3 inches. (From Snodgrass. Courtesy U. S. Dept. Agriculture.)

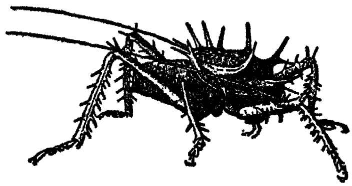
But it is with insects that we see the most remarkable instances of protective coloration and far more of protective structure. We have only to think of the walking-sticks and the leaf insects and those extraordinary Indian butterflies which when their wings are folded resemble dead leaves. And equally striking examples occur almost unnoticed all around us. There are caterpillars, known as measuring-worms, that hold themselves at the proper angle from the twigs upon which they are crawling, and from their color and position might be mistaken

Two bag-worms in their disguised cases on a twig of arbor vitæ. Not only does the stout bag shield the larva, but it is an instance of special protective resemblance.

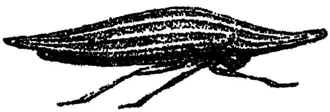
The so-called "hickory-horned devil"—larva of *Citheronia regalis.* (Photograph by John Howard Payne.)

for twigs, themselves. There are caterpillars that in coloration and form look like the droppings of birds. There are beetles that when disturbed

A grouse locust—*Cladonotus latiramus* (grasshopper family)—from Ceylon, strangely suited to its environment. (After Berlese.)



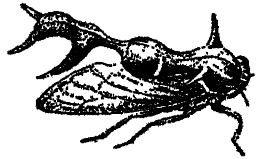
An African katydid—*Cosmoderus erinaceus*—that has come to resemble the thorny vegetation on which it lives. (After Berlese.)



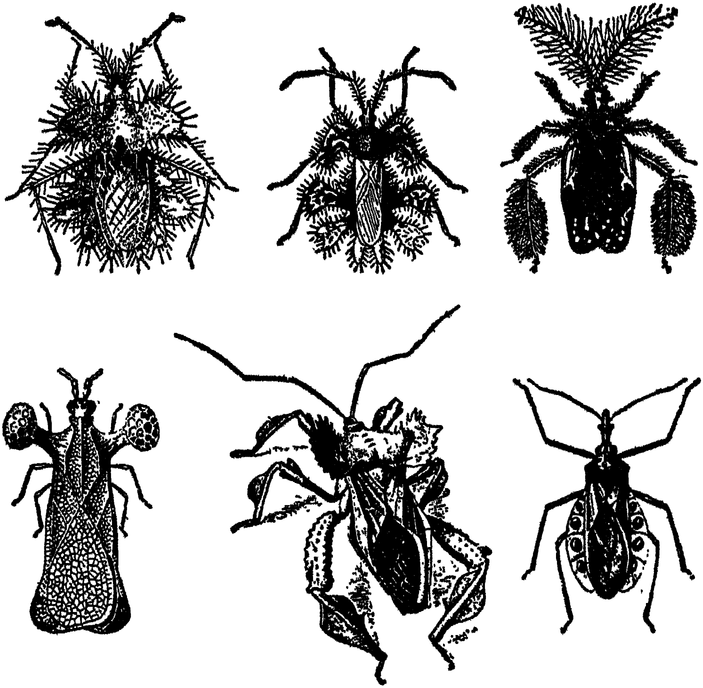
A Mexican leaf-hopper—*Polyglypta costata*—closely resembling the plant on which it lives. (After Berlese.)

draw their legs beneath them and would pass for bits of stone or earth. There are leaf-hoppers that in coloration and form resemble the thorns of plants on which they live.

In fact, an observing person cannot take a walk in the woods or fields on a summer

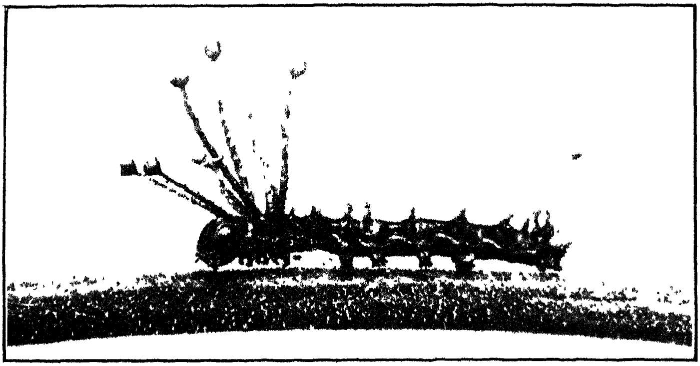


A Brazilian leaf-hopper—*Heteronotus flavolineatus*—whose body has developed spines resembling those of the vegetation on which it lives. (After Berlese.)

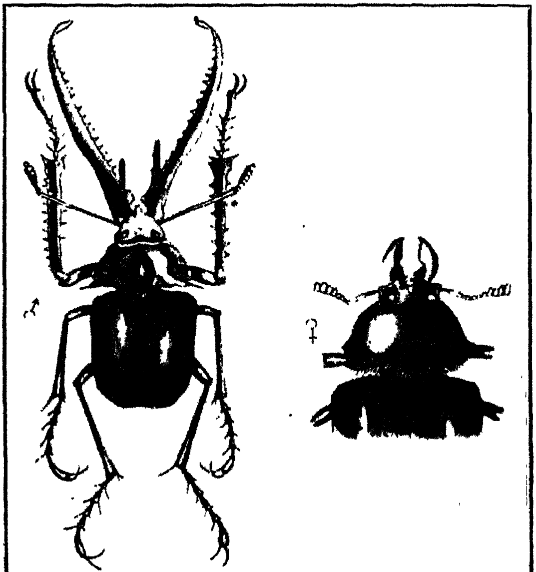


Strangely modified heteropterous insects—true bugs. (After Berlese.)

day, here in the United States, without seeing countless instances of the sort. We need not go to India for butterflies almost as wonderful in this respect as the Kallima first described by Alfred Russell Wallace, since many of our native Vanessas, like the Comma butterfly or the Violet-tip, although conspicuous enough when flying, when they alight and fold their wings are virtually indistinguishable from the bark of the



Newly hatched larva of the "hickory-horned devil"—*Citheronia regalis*. In this stage the horns on the thorax are enormously long, and each has a more or less bulbous knob. These are probably protective in function. (Photograph by John Howard Payne.)



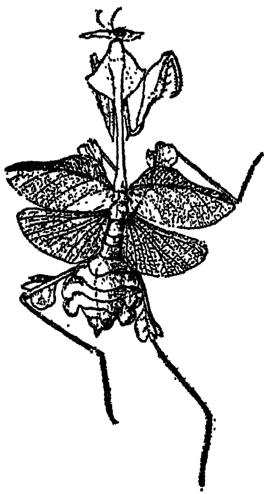
A tropical beetle—*Chiasognathus Geantii. Male* with long jaws and head, and thorax of female. (After Darwin.)

tree upon which they happen to rest. The same may be said of the under-wing moths.

Then too there are the so-called aggressive resemblances—the resemblances that many predatory insects have to parts of plants or flowers and that conceal them while they seize other insects that approach unsuspectingly. Beautiful examples of this will be found in the so-called Flower Mantids of the tropics, which so closely resemble flowers attractive to certain insects that they are helped enormously in catching their prey. There are spiders also that are colored like the flowers they frequent, lurking until flower-visiting insects approach, when the latter are captured.

And there is yet another kind of coloration, known as the warning coloration, which seems to have been developed by certain insects distasteful to birds—a brilliant coloring that enables the birds to recognize them at a glance and avoid them.

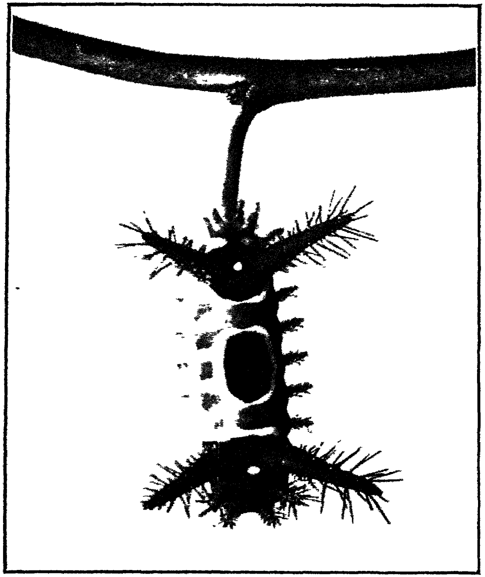
Some perfectly defenseless insects have grown to resemble closely other insects that have various means of defense, such as stings, and are therefore avoided by their natural enemies. Many defenseless flies resemble stinging bees and wasps, and thus enjoy immunity from attack. Others look like ants. Moreover, nauseous forms supplied with bright warning colors are mimicked by others which might otherwise be eaten by birds and reptiles. Many tropical butterflies are mimicked in a way that seems inexplicable except on the supposition of protection. The famous English entomologist Professor E. B. Poulton of Cambridge has written much about these forms and on the general subject of mimicry and protective resemblance—a subject, in fact, which has been treated by a great number of observers, investigators, and writers.



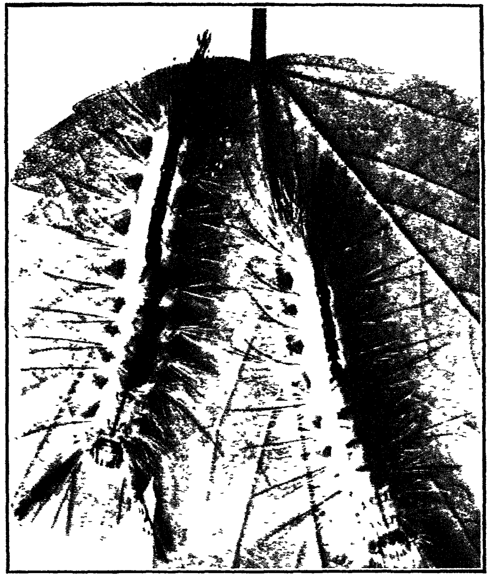
A tropical praying-mantis of leaf-like appearance. (After Berlese.)

Other kinds of protection have been developed by insects. Some larvæ cover themselves with slime secreted from the pores of their bodies; some, like the caddis-worms and the bag-worms, build cases in which to live; and of course numerous insects during their pupal, or quiescent, stage are protected by strong silken cocoons or other structures. There are caterpillars that have well-developed stinging spines.

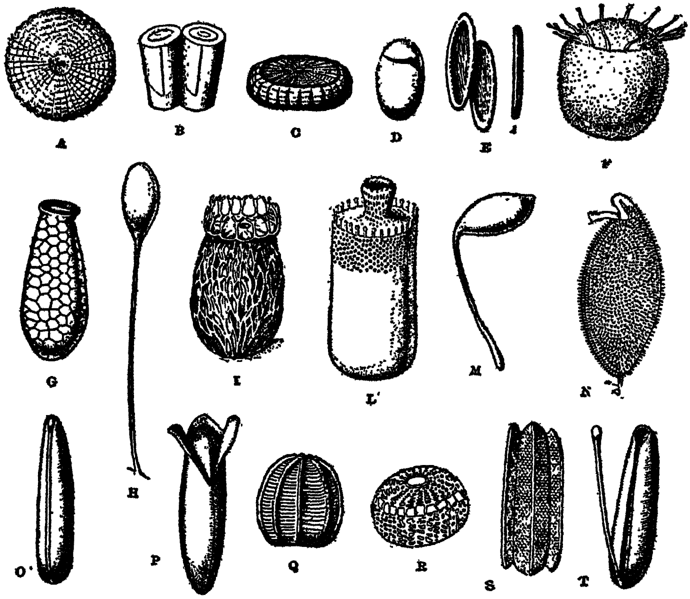
In short, the protective devices to be found among insects are almost beyond number. There are butterfly larvæ that throw out from their



One of the nettling caterpillars. Full-grown larva of *Empretia stimulea.* (After Weigel and Middleton, U. S. Dept. Agriculture.)



A full-grown larva of the white-marked tussock-moth—*Orgyia leucostigma*—a common shade-tree pest that has "nettling hairs." (After Quaintance and Siegler, U. S. Dept. Agriculture.)



Eggs of different insects. Note especially, at *H*, the egg of an aphis-lion, mounted on a long stalk so that the newly hatched larva cannot easily reach and destroy its brothers and sisters. (After Berlese.)

anterior segments fleshy horns of a terrifying aspect and a disagreeable odor. Certain ground-beetles have developed the faculty of puffing out from the anus what seems to be an explosive cloud of smoke; hence they are called the bombardier-beetles. And probably the brown "molasses" that exudes from the mouth of a grasshopper when it is picked up is a protective excretion.

We have thus briefly considered minute size and power of concealment as elements in the persistent existence of the insect type. Perhaps not less important than these are the extraordinary powers of multiplication. We know very well the enormous prolificacy of certain fish and how some species remain exceedingly numerous despite the fact that incalculable numbers of their eggs and young are eaten by other fish; but in power of multiplication many insects take an even higher rank—not so much, perhaps, in the number of eggs laid as in the rapidity with which generations succeed one another. And by the way, it is this rapidity of development that makes some of the insects so valuable in the study of problems of inheritance. (Note the importance of the little flies of the genus Drosophila in the laboratories of the world.)

Many startling instances have been given by different writers. I have shown, for example, in my book on the house-fly, that in the latitude of Washington, D. C., a single over-wintering female may have, by the last of September, 5,598,720,000,000 descendants, and all in about four or five months.

Most insects have large numbers of eggs. These eggs are of every possible kind, and are so constructed and protected that they can withstand all sorts of adverse conditions. In the case of some forms, it is interesting to note that they are protected not only against the attacks of other insects but against cannibalism among themselves. Witness the habit of certain of the lace-wing flies of laying their eggs on long stalks. Then too, many insects, like the plant-lice, give birth to living young, and for many generations the fertilization of the female is not necessary. A plant-louse is born, and in a few days begins to give birth to young; so that there is almost nothing in nature that can approach plant-lice in rapidity of reproduction. There are insects which, strangely enough, do not even have to become full-grown before beginning to reproduce. There are certain small flies and, as has been shown by Herbert S. Barber, a small beetle whose larvæ give birth to other larvæ.

In considering the astonishing powers of multiplication of insects, we must remember that not only do they have a multitude of young but with the majority of species the growth of the individual is extremely rapid, and the two things together help to account for the remarkable number of individuals. And, too, growth and development are really isolated, the one from the other, by the physiological process known as metamorphosis. Growth goes on to a certain point; then there is a physical change to another stage.

The importance of the rapidity of growth must be further stressed, since notwithstanding their small size the actual bulk of insects, through this rapidity, becomes enormous. Dr. David Sharp observes:

> Let it be supposed that growth of the individual takes time in proportion to the bulk attained, and let *A* be an animal that weighs one ounce, *B* a creature that weighs ten ounces, each having the power of producing one hundred young when full-grown; a simple calculation shows that, after a time necessary for the production of one generation of the larger creature, the produce of the smaller animal will enormously outweigh that of its bulkier rival. Probably it was some consideration of this sort that led Linnæus to make his somewhat paradoxical statement to the effect that three flies consume the carcass of a horse as quickly as a lion.

Accounts of the ravages of grasshoppers, or "locusts," have been published by the hundreds, and a faint idea of the numbers of individuals in a single swarm can be gained from these accounts. Comparatively few eggs are laid by a female grasshopper, or "locust," and there is but one generation each year, and yet their numbers often exceed human powers of computation. And when we look at species of which each female lays hundreds and even a thousand or more eggs, and species that produce many generations each year, the wonder is that there is room on

One day's collection—September 7, 1888—of locust eggs in Algeria. (From Künckel d'Herculais.)

The Old World locust on a wall in Jerusalem during the locust plague of 1915. (Photograph by American Colony photographers, Jerusalem. Courtesy of the National Geographic Society.)

earth for any other kind of life. Surely there would not be if the surplus were not killed off or if the available food were not exhausted and they did not die from starvation by millions.

But when we read of such notorious insects as grasshoppers or plant-lice we are inclined to say, "We know all that—we have thought of that—it is an old story," and the actual situation fails to make its full impression. A published note by Mr. R. P. Dow (in the "Journal of the New York Entomological Society," September, 1924) really gave me to think, as the French say, more of this serious aspect of the insects' advantages over the human species than any of the well-worn stories of vast invasions of grasshoppers or army-worms or of the possible filling of the world by a mass of rapidly developing plant-lice.

Mr. Dow noticed a migration of the thistle-butterfly in southern California in the spring of 1924, and he did some counting. At any given point of space he could count from fifty to one hundred a minute, flying at a rate of fifteen miles an hour from dawn to darkness over an area of one thousand square miles. There were, therefore, living at one time in three southern California counties more thistle-butterflies than there were human beings in the whole world. And the thistle-butterfly is only one of thousands of unconsidered species. And what Mr. Dow has told us of this butterfly could be stated concerning hundreds upon hundreds of injurious forms.

The people who inhabited the promised land of Israel were apparently able to form a very just estimate of the menace of injurious insects from the way in which various species swarmed there. No one has expressed it better than the prophet Joel when he said:

> That which the palmer-worm hath left hath the locust eaten; and that which the locust hath left hath the cankerworm eaten; and that which the cankerworm hath left hath the caterpillar eaten. . . . For a nation has come up upon my land, strong, and without number . . . He hath laid my vine waste, and barked my fig tree . . . The field is wasted, the land mourneth; for the corn is wasted: the new wine is dried up, the oil languisheth . . . the apple tree, even all the trees of the field, are withered . . . Alas for the day! for the day of the Lord is at hand, and as a destruction from the Almighty shall it come.

Among insects we find a host of adaptations in structure and in habits which make for the preservation of the young, entirely aside from the protection or concealment of the eggs, and all of these help in the enormous powers of multiplication.

The average person who is interested in watching insects, and even many skilled ento-

Country-house garden showing vegetation just before a visit by locusts, in the Argentine. (From L. Bruner.)

Same garden as shown in preceding figure, four or five days after locust invasion. (From L. Bruner.)

mologists, get into the habit of considering that insects lay their eggs in such situations that the larvæ which hatch from them will be immediately supplied with food—that these larvæ are for the most part so helpless that they must find sustenance readily available. One sees this with virtually all the butterflies and moths, and with the beetles and grasshoppers and most other insects. But in the course of evolution there has developed here and there an extraordinary adaptation that gives to the newly hatched larvæ of some insects the structure and the power immediately to begin a search for food which may require much effort and some time.

In some groups it is obvious that this may have been, if not a primitive habit, still a very early one. Think of the little fat white grubs in the interior of seed, like the larvæ of the bean-weevil, for example. There seems to be no need for locomotion and no use for legs, even if the larvæ possessed them, and in fact when one sees them they are legless and motionless except for power to squirm and move their jaws. But when these larvæ are first hatched they possess rudimentary and probably functionless legs which are apparently of no use to them and are simply vestiges of limbs once functional in the past history of the species.

With the mites, which are not true insects, there comes a stage in growth when Nature permits them to remain for a long time without food. Many of them never reach food; others are so constructed that they can attach themselves to an accidental visitor, in the shape of some insect, by which they are carried to the vicinity of cheese or other food.

Among the blister-beetles, the larva goes through several radically different stages. With some of them, when first hatched the larva is very active and possesses strong grasping legs by which it is enabled to cling to the leg of a female grasshopper and be carried by her until she lays her eggs, when it drops off and grows in the egg-case of the grasshopper, feeding upon the eggs. Or it will attach itself to the leg of some bee and be carried away to the bee's cells and there feed upon either the stored food supply or upon the bee larvæ.

With a number of the Hymenoptera something similar happens, and there is an active first larval stage which is migratory so that the larva can gain the proper place to feed.

We all know how insects are carried by commerce; how mosquitoes were originally introduced into Hawaii, for example, on sailing-ships from the United States, since they used to breed in the water supply of such vessels; and how, in older times, the yellow-fever mosquito was brought up from the West Indies to Philadelphia and even to Halifax in the same way and bred through the summer in those Northern cities in the rain-water barrels on the wharves. Now insects use all sorts of conveyances—not alone steamships, railway trains, automobiles, and even airplanes, but also the clothing of human pedestrians, the feet of birds, and flying insects. Moreover, many of them have become adapted to specific carriers among other insects.

A beautiful adaptation of this kind occurs with a little parasite of the eggs of the European praying-mantis. The winged adult of the parasite, according to the French writer Chopard, attaches itself to the body of the female mantis, gnawing occasionally at the bases of her wings. As soon as the mantis sets herself to lay her egg-mass, the parasite runs down to the end of the mantis's abdomen, and as the host's eggs are laid she thrusts her own eggs into them.

Almost exactly the same thing is done by a minute parasite of a plant bug which injures vegetables in the Belgian Congo, according to Ghesquière, with the added touch that the adult parasite first attaches itself indiscriminately to both males and females of the bug, changing to the female only during the act of coupling.

The migration of the parasite to the end of the abdomen of the host insect just as the act of egg-laying is about to begin reminds us of the striking observation made by Marlatt, many years ago, on the horn-fly. The larvæ of the horn-fly live in fresh cow dung, while the parent flies live upon the cows, sucking their blood, and preferably toward the head of the animal. But Marlatt noted that as soon as a cow sets herself to drop her excrement all of the gravid flies on the body instantly migrate to the region of her anus, and as soon as the dung falls they are upon it and have laid their eggs, returning immediately to the cow.

It is difficult not to write on and on about these remarkable things which make for the ability of insects enormously to increase, but there is so much to be said in a broader way that I must repress an almost irresistible desire to continue the description of illustrative cases.

Literally hundreds of accounts will be found in books about the abundance of insects from time to time and in different parts of the world. It is not necessary to quote even the most striking. Most people have read one or more of them. In temperate North America comparatively few such cases have been described by writers, and nothing of a generally spectacular nature has happened since the days of the Kansas and the Colorado grasshopper in the 1870's, if we except the occasional dramatic appearance of a

A flight of locusts over an island of the Sulu Sea, Philippine Islands. (Photograph by Charles Martin. Courtesy of the National Geographic Society. Reproduced by special permission from the National Geographic Magazine.)

brood of the periodical Cicada, or so-called seventeen-year locust. But the Western farmer who has seen his crops wiped out by the chinch-bug or the army-worm or the Hessian fly needs no elaboration of this theme.

A homely, everyday instance of prolificacy occurs to me and may be mentioned. On two occasions Dr. Otto Lugger counted the mosquito eggs and larvæ in a single rain-water barrel. The average number was 18,235. That one rain-water barrel, therefore, would send out during the summer at least 130,000 mosquitoes, and considering their probable offspring, if they found suitable breeding-places, the barrel was initially responsible for a mosquito population of the neighborhood running into the billions.

Possibly no instance that I can think of will be more striking to the average individual than Professor Herrick's recent estimates regarding the possibility of the little aphis, or plant-louse, that lives upon the cabbage. Herrick weighed an individual aphis and calculated its increase in a season. In central New York (the experiment was carried on at Ithaca) he showed that, were there food enough, this single aphis would have in a season so many descendants that, although each one weighs little more than a milligram, the ponderable mass of the whole would weigh more than 822,000,000 tons. In pounds, this would be 1,644,000,000,000. Estimating the human population of the world at 2,000,000,000, and the average weight of individuals at the greatly exaggerated figure of 150 pounds, we have the total of human weight 300,000,000,000 pounds. In other words, the plant-lice descended from one individual in a single season would weigh more than five times as much as all the people of the world.

Such astonishing things as this could not happen if it were not for the phenomenon of virgin birth (parthenogenesis). A virgin female only a few days old will begin to give birth to living young at the rate of one or more a day. And there is another unique phenomenon. With certain insects a large number of individuals may develop from a single egg. Fortunately, most of the species in which this occurs are beneficial forms, parasites of other insects. It seems almost impossible to believe, but from a single parasite egg a whole chain of embryos may develop. I have known nearly three thousand adult, active parasites to emerge from a single caterpillar, and yet the original eggs laid by the adult parasite in the caterpillar were probably not more than a dozen at the most.

Furthermore, there is a phenomenon known as pedogenesis, in which larvæ give birth to other larvæ, just as though a human child were to give birth to another child. This occurs with certain flies. There are other strange things that should be mentioned. For instance, there are numerous insects that do not lay eggs. There are many insects that not only do not lay eggs, but whose larvæ live in the body of the mother until they are virtually full-grown before they emerge to the outer air. There are insects that pass to the pupa or nymph stage while still within the body of the mother, and there is a large group of flies that, from this process, is known as the *Pupipara*. To fill out the catalogue of extraordinary happenings connected with reproduction, there is at least one case in which a pupa itself lays eggs.

Aside from these phenomena actually connected with reproduction, there are other astonishing things concerning the growth of the young of those forms which really lay eggs. There are numerous groups of insects in which occurs what is known as hypermetamorphosis; that is, after each molt, a larva assumes the form of the larva of some entirely different order of insects. This phenomenon is noticed especially in certain groups in which the larvæ have a parasitic function. It is particularly marked, for example, with the larvæ of certain blister-beetles, the story of which has been told so well by Fabre and other popular writers.

Dr. David Sharp's statement, "The larger part of the animal matter existent on the lands of the globe is in all probability locked up in the form of insects," is undoubtedly true, as is also his further statement, "Taken as a whole they are the most successful of all the forms of terrestrial animals."

Considering the powers of rapid multiplication the insects possess, it is obvious that if there were only a few different kinds and these were all injurious to man's interests, they would still be extremely redoubtable enemies; but in addition to the multitude of individuals that may be produced under favorable conditions there is a vast number of different species.

It is generally recognized that the different kinds of insects outnumber all the other kinds of animals put together. The statement is frequently made that there are more different kinds of insects in the world than there are of flowering plants. Both of these statements are probably correct, and it may well be that the numbers of insects are vastly greater. It is impossible, really, to make any reasonably approximate estimate of the number of species, for it is surely true that only a small proportion of them have been secured and named and preserved in the great collections. A few figures have been brought together, however, which are suggestive.

In 1919, Aldrich estimated the number of specimens of insects in the collection of the United States National Museum as somewhat exceeding 2,000,000, representing about 99,000 different species. Several books published within the last ten years have made the statement that about 300,000 species of insects have been described, but the basis for this estimate is not evident. It has been estimated that 6,500 new species of insects are described every year by the specialists on the different groups of insects. This is probably approximately accurate; but when I stop to think that, on this basis, during the years since I began my work in Washington in 1878, 338,000 species have been described, it makes the published estimate of 300,000 described species for the world seem absurdly small, since surely some hundreds of thousands of species were described before that time.

The number of species existing in the world, described and undescribed, has been variously estimated. Dr. David Sharp of England said in 1883, "As the result of a moderate estimate, it appears probable that the number of species of true insects existing at present on our globe is somewhere between five hundred thousand and one million," and adds, "The number probably exceeds the higher of these figures and will come near to two millions." In 1889, Lord Walsingham, in his presidential address before the Entomological Society of London, concurred in Dr. Sharp's estimate. In 1892 the late C. V. Riley thought about this matter and concluded—after considering the fact that the species already collected are mostly from the temperate regions of the globe and that many portions of the world are as yet unexplored by collectors of insects, and further that the species in many groups of insects are apparently unknown—that the estimate of 2,000,000 species in the world, made by Dr. Sharp and Lord Walsingham, was extremely low and that it probably represented not more than one fifth of the species that actually exist. Riley's estimate, then, was 10,000,000.

When this estimate of Riley's was published, so far as I recollect, it met with no favorable comment. Every one thought that it was too high. Some competent biologists said they did not believe that Professor Riley realized what a million meant. As a matter of fact, very few people, aside from the astronomers and mathematicians and possibly the geologists, realized the meaning of so vast a figure, especially before the late World War. But there are many things to be taken into consideration, and it is quite possible that Riley was nearer right than his English contemporaries.

Nearly thirty years ago the late W. H. Ashmead, who knew very well the insects of one of the great orders, estimated that there are 1,000,000 species of parasitic Hymenoptera in the world, of which only 10,000 had been named up to that time; and yet the parasitic species include only three or four families of the great order Hymenoptera. I imagine that Dr. Ashmead's idea of what a million means may have been as inadequate as some critics considered Professor Riley's, but we must believe with him that the number of species in the group he had in mind is tremendous.

I brought up this question of the number of species once, at a meeting of the Entomological Society of Washington. The meeting was well attended by a number of experts, and the discussion was extremely interesting. One authority who had studied the Hymenoptera about which Dr. Ashmead had expressed his ideas, Mr. Rohwer, believed that 90,000 would be a fair estimate of the number of described species. He said that, to be conservative, he would multiply this number by three so as to get a good estimate of the entire number of species in the world. That would give a total of 270,000. Dr. Aldrich estimated the number of Diptera in the world at 220,000 species. Mr. H. S. Barber, speaking of the Coleoptera, thought that 200,000 species had been described, and expressed the opinion that we know less than one tenth of the existing number of species. In speaking of the beetles, another coleopterist, Mr. Fisher, stated that the small species of one family from Malaysia that he had studied contained about 90 per cent new species, and that in another collection from the Canal Zone about 75 per cent of the species were new. Mr. Caudell expressed the opinion that there were about 20,500 described species of Orthoptera. Mr. Bridwell, who had collected largely in the tropics, believed there were 100,000 species of beetles in Australia alone. He thought that Mr. Rohwer's estimate of the number of Hymenoptera was far too conservative.

It may be of interest to note that Dr. Snyder stated that there were about 1,000 known species of termites, or white ants as they are sometimes called, and that in his opinion there may possibly be 5,000 species in the world.

It seems to me that because of the character of the men who took part in this discussion it was probably the most authoritative expression of opinions that could very well be had. And it would not surprise me in the least if it should be shown that more than 4,000,000 species of in-

Gipsy-moth caterpillars ascending the trunk of a tree and stopped by a sticky band. (U. S. Dept. Agriculture.)

sects exist, and this vast number of species, added to the other factors with which we have already dealt and those with which we shall deal, intensifies our conception of the magnitude of the task before us when we realize that we must know all about them.

Chapter III

WHY THE INSECT TYPE HAS PERSISTED (CONTINUED)

WE HAVE already seen, on our mention of Chetverikov's paper, how the insect legs are three times stronger than ours because the skeleton is on the outside and not on the inside. Then, also, the substance of which the skeleton is composed is of great advantage. It is a peculiar substance that looks like horn. It was given the name *chitine* by a French scientist named Odier more than a hundred years ago. It is an albumenoid and differs from horn in important particulars. It burns without shriveling, and is attacked neither by alkaline solutions nor by dilute acid. It contains no sulphur as does horn, and it does not grow brittle with age like the bones of vertebrates.

This substance, thin or thick, covers and protects the insect's entire body. With us the muscles are exposed to the slightest injury, being attached to the inner bones; but with the insects they are covered by the chitinous skeleton, and they function better from their numerous attachments to ridges on the inner side of the chitinous covering. The outer skeleton of insects is, in fact, of tremendous advantage. It is virtually unbreakable. It bends, and it is lighter and stronger than bone.

We shall speak later of the diet of insects, but in writing of the skeleton it should be pointed out that insects make much better use of their waste products than do the vertebrate animals and that much of their skeleton is composed of waste material which is thus employed instead of being expelled from the body.

It should also be said here that the different kinds of wax secreted by many species and used by them for protection, or, as in the case of bees, as combs and food for their young, are also waste bodily products that serve vital purposes.

A further superiority of the skeleton of chitin over the skeleton of bone has been pointed out to me by Dr. Charles H. Richardson. Chitin, considered chemically, is a complex of nitrogenous sugar groups, while the bony skeleton of man is composed largely of proteins and inorganic materials, chiefly lime and phosphorus. Now, it happens that the starches and other substances that will make the chitinous skeleton of insects, abound in nature, while man's diet must be carefully selected so as to include the substances needed in the growth of bone. So the task of the human being is much more difficult than the insect's.

Chitin is a substance which lends itself marvelously to all modifications of bodily structure, and perhaps especially to modifications of the limbs. The leg of any insect is a wonderful thing, and with each group and each species the leg in all its parts has been adapted to the precise method of life which the species has adopted. We find the most extraordinary running legs, legs modified for jumping, legs adapted to the grasping habit, legs developed into oars for swimming, legs beautifully constructed for digging in the most effective way. And not all of the three pairs of legs of the same insect are developed in the same way or for the same purpose. The front pair may be modified into powerful grasping or crushing tools, leaving the middle and hind pairs for walking; or the front pair may be used for digging, and the hind pairs for walking.

Further than this, the different parts of the same legs may be modified for different purposes or functions; as, for example, in the hind leg of the common honey-bee the second segment is modified as a carrier, or basket, for pollen, and is made very effective by the modification of the hairs to form a rim. The inner side of the first joint of the foot is modified to form a

Defoliation from the work of gipsy-moth caterpillars, eastern Massachusetts, 1904. (U. S. Dept. Agriculture.)

comb of sharp stiff hairs for removing wax scales from the wax pockets of the under side of the abdomen. The articulation between the two segments is modified as a loading apparatus for pollen.

And the other legs of the honey-bee are modified so as to be usable as tools as well as for walking. On the front legs, for example, is an antenna-cleaner consisting of a spur on the tibia and a comb-like modification of the tarsus; while on the far end of the tibia of the middle leg is a spur which is used in prying off the pollen load from the "pollen basket" of the hind leg.

The front leg of a mole-cricket is an especially remarkable tool. It is beautifully adapted for burrowing under the ground (and the mole-crickets live most of their lives underground), and at the same time, if the insect encounters water, the leg functions admirably as an oar, just as a man, if he were put to it, could use a shovel as an oar. The insect lives not far below the surface of the ground, and the end segments of the legs have been modified so as to act as shears—far more effective than real shears would be—whenever it may be necessary to sever a root. One strange thing about these front legs is that just below the knee is the ear, contained in a slit in the skin.

In fact, the legs of virtually all insects have become especially modified so as to be supremely useful. The insects have not the intelligence to invent tools, but the needs of their existence have developed their own organs into highly specialized tools.

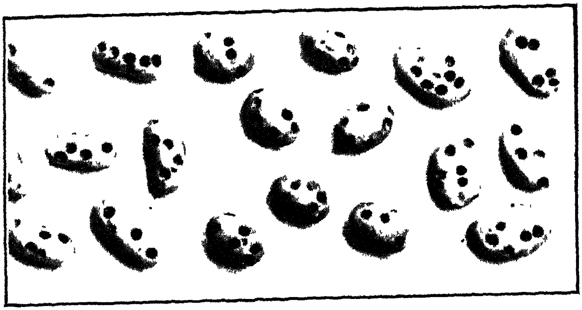
My colleague Dr. McIndoo has suggested to me the pretty though fantastic idea that if various groups of people were anatomically as well adapted as are various groups of insects it would not be necessary for man to develop his mind to so high a degree. For the sake of using all of the available food to the best advantage, certain groups might be purely vegetarians, others purely carnivorous, and still others might eat the other things. If one group had the legs of a mole-cricket, another the legs of a water-beetle, another group the legs of the grasshopper, another the legs of a tiger-beetle, another the wings of a bee, another specially modified breathing apparatus for use under water, we should have less need of all our modern methods of transportation and communication.

As it is with the legs and the other external organs, so it is with the internal organs. The muscles of an insect function much more efficiently than do those of a vertebrate animal. A man would be able to jump an eighth of a mile if he could leap as many times his own length as do certain insects. The nerve-centers of an insect are distributed throughout the whole length of its body instead of being concentrated in its head. Its breathing tubes penetrate to every part of the body instead of being concentrated as are our lungs; hence the obstruction of a tracheal branch is not a serious matter. It is much the same with the circulatory system of the insects. The heart, or so-called dorsal vessel, extends for the whole length of the body instead of being concentrated in the thorax. There are no small arteries or veins; and a slight wound, even to the heart itself, never causes death from bleeding.

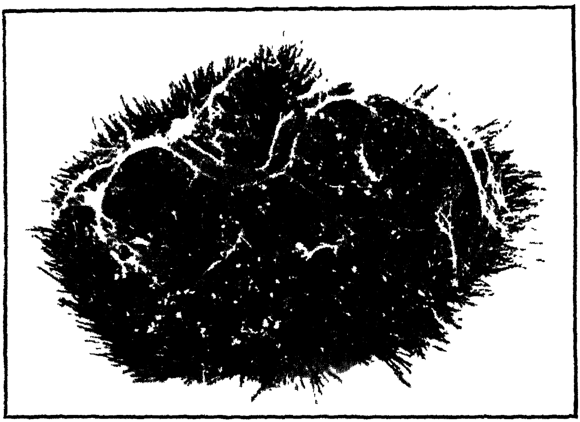
With all these anatomical advantages it is not strange that insects seem to be less susceptible to disease than are the higher animals, although they have their internal parasitic diseases, caused by micro-organisms and toxins, that sometimes carry them off in great numbers, as notably the silkworm disease known as pébrine which at one time threatened the extinction of the domestic silkworm of commerce until one of Louis Pasteur's early discoveries came to the rescue.

Nothing shows more strongly the advantage of the insect type—not even the very highly developed and extraordinarily diversified structural adaptation—than the adaptations that have come in the course of the ages to different kinds of food. Thousands upon thousands of species live upon live plants. There is hardly a plant that does not have its insect enemies; and some cultivated crops are eaten by very many species of insects. For example, the apple is said to have five hundred species of insects feeding upon it, and virtually every cultivated crop has its scores, and, in some cases, hundreds of different kinds of insect enemies. In this way insects encroach tremendously upon our own food supplies. Thousands of species are carnivorous, most of these, fortunately, feeding upon other insects. Many of these carnivores feed upon dead animals, and these from man's standpoint are scavengers. But still others attack living vertebrates in one way or another, sometimes as insignificant but dangerous parasites, and sometimes as bloodsuckers and carriers of disease, like mosquitoes, gadflies, tsetseflies, and so on.

But if all the higher plants and all the higher animals were annihilated, there would still be hosts of insects, for there are forms that feed upon a great variety of things. Hundreds of species live underground and feed upon soil humus; hundreds of others live in the water, feeding upon the microscopic organisms that swarm



Navy beans showing emergence holes of weevils. The five small beans at the bottom were grown in Central America and were infested by the Mexican bean-weevil; the rest were injured by the common, cosmopolitan bean-weevil. (After Back, U. S. Dept. Agriculture.)



End of a shaving-brush showing a well-developed larval tube of the Southern, or webbing, clothes moth. (After Back, U. S. Dept. Agriculture.)

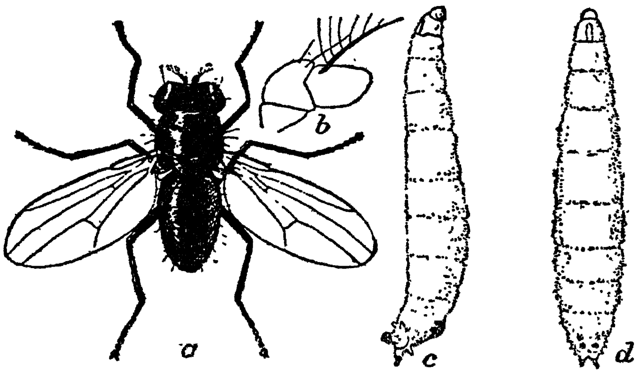
there, or upon other insects. Those that live in dead wood, in garments and rugs and carpets made of wool, in virtually all of our stored foods of different kinds, those free-lances like cockroaches, born invaders and feeders upon all sorts of things to be found in houses, bookworms, the drug-store beetle which accommodates itself to the conditions existing in apothecary shops and which eats everything, from face powder to Spanish flies, Cayenne pepper, mustard plasters, and even weak insect powder—all these are examples of the ability shown by the insect type to adapt itself to different foods.

And this is only the beginning of the story. The strongly alkaline lakes in our Western States, of which Great Salt Lake in Utah is the largest, support virtually none of the common types of organic life, yet at times they almost swarm with the maggots of the curious group of Ephydrid flies. These strange flies breed in water so alkaline as to kill almost all other forms of life, and there are many species in the group. Some are known to live in the salt-mines in Bohemia. One was described in full recently in one of the Cornell University publications and it was found in the salt-wells near Ithaca. Another occurs in abundance in the badly cared for *lieux d'aisances* in European cities, and—wonder of wonders—still another breeds in the petroleum around the openings of the oil-wells in California. And yet petroleum is used all over the world to destroy most insects.

These flies that breed in the strongly alkaline waters and the one that breeds in petroleum all belong to a family known as the Ephydridæ. None of them have been studied as carefully as their strange habits seem to warrant. Quite recently the petroleum fly, living as it does in the larval stage in shallow pools of waste oil and found as yet only in southern California, has been carefully studied by Mr. W. H. Thorpe, a young Englishman who has spent some time in that locality, and he has published his results in the journal "Science" for January 23, 1931.

These larvæ breathe by means of posterior spiracles which they project above the surface of the oil at will. They and their close relatives must have a very dense skin that is not affected by the oil or by the alkalies. The question as to what they can find of a nutritive nature in the thick oil in which they live is of interest. I wrote about them over thirty years ago, and offered the suggestion that they subsist on the remains of other insects that have been caught in the oil. The subject was studied later, in 1912, by D. L. Crawford, now President of the University of Hawaii, and he found that young larvæ could be reared to maturity in filtered and sterilized oil without any extraneous organic matter, the inference being that they could derive their energy from the digestion of hydrocarbons.

Although, as we have indicated, insects appear to be able to digest almost everything, this conclusion seems so astonishing that Mr. Thorpe



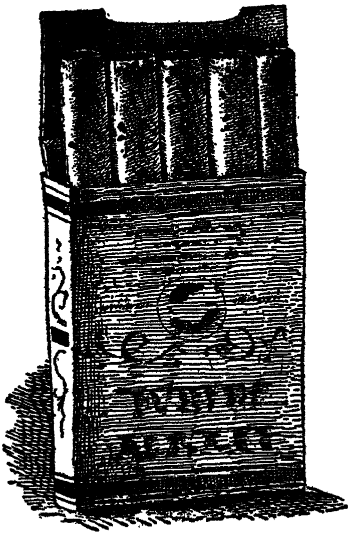
The petroleum fly—*Psilopa petrolei*—*a*, adult; *b*, antenna greatly enlarged; *c*, larva from side; *d*, larva from above. (Author's illustration.)

went into it carefully in an experimental way. He decided that my initial idea was right, that these petroleum larvæ really feed upon the remains of other insects caught in the oil and that in experiments where such matter is excluded certain of them derive their nourishment from the bodies of their companions as the latter die.

Although the skin of these larvæ is so tough that the oil cannot penetrate it, experiments with more volatile oils showed that when once the oil enters the tracheal system of the larva and comes in contact with the tissues, it is as poisonous to this insect as to any other. Nevertheless in the course of its feeding the alimentary canal is filled with oil from one end to the other. Why, then, does the oil not reach the tissues by absorption through the walls of the food canal? Mr. Thorpe finds that it never comes in contact with the epithelium of the gut. The fore and hind guts are protected by a chitinous layer, and the mid-gut possesses what is termed a peritrophic membrane that is very well developed and through which the oil does not pass.

Mr. Thorpe asks what change has taken place in the composition of the digestive juices in order to enable them to act upon food saturated with petroleum. This is a question that one trained in biochemistry must answer some day.

Aside from those forms that suck the blood of man and animals, a great many of which are carriers of disease germs, and aside from the excessive number of species that feed upon growing plants, I have jotted down a list of substances that are of value to us and upon which certain insects feed. These are, ham, cheese, salted fish, butter, lard, dried mushrooms, dried bread, sweetmeats and preserves, powdered coffee, almonds and other nuts, raisins, breakfast foods, chocolate, ginger, rhubarb, black pepper, vinegar, sugar, wines, canned soups; tobacco, snuff, licorice, peppermint, aromatic cardamom, aniseed, aconite, belladonna, musk, opium, ginseng, camomile, boneset; hides; shoes, gloves, and other leather articles; furniture, carpets, drawings and paintings, books, photographs, paint-brushes, gun-wads, combs, etc. (made of horn; hay, oats, straw, willow baskets; ladders, wheel-spokes, ax-handles, and all sorts of agricultural instruments with wooden handles; barrels, wine-casks, corks of wine-bottles, sheets of cork; natural-history collections, including skeletons and mummies.



Cigarettes damaged by the cigarette beetle—*Lasioderma serricorne*. (Author's illustration.)

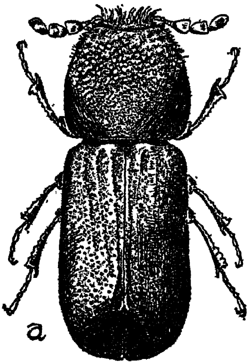
To this long list must be added, of course, all kinds of stored grain and many other articles of dried food. It is true that insects have been known to bore through the sheet-lead linings of old-style water-tanks and through the lead sheathing of electrical cables, but lead is not a real article of diet, and in such cases it has been pierced by beetles that lived in dead wood immediately adjacent.

There was published many years ago a picture of an old lead Minié ball found after the Civil War in the trunk of an oak tree, where one of the oak-borers had bored through it. This old picture is reproduced here.

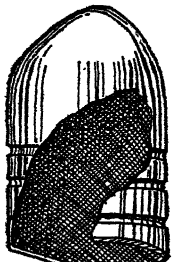
We must say something more about damage to the lead coverings of telephone cables. Such damage by insects has been reported from China, Australia, California, and Brazil. In Pernambuco the telephone service suffered seriously from the activities of a handsome beetle that deposited its eggs in the cable sheathings, where the hatching larvæ bored into the lead, trying to start tunnels.

In California it is another kind of beetle that makes trouble. It is a wood-borer, like the Brazilian form, but belongs to an entirely different family and is very much smaller. (It is shown here greatly enlarged.) It attacks cables during the summer season, from time to time, and does a good deal of harm. The boring is done near the point of contact with the cable and the rings that suspend the cable from the messenger strand that supports it.

The apparently eccentric diet of the so-called white ants, or termites, deserves special consideration. These creatures seem to eat a great many things, but when we come to look into the matter carefully we find that, after all, what they eat is cellulose. We know that they destroy



California lead-cable borer—*Scopicia declivis.* Lec. Adult beetle, greatly enlarged. (After Snyder.)

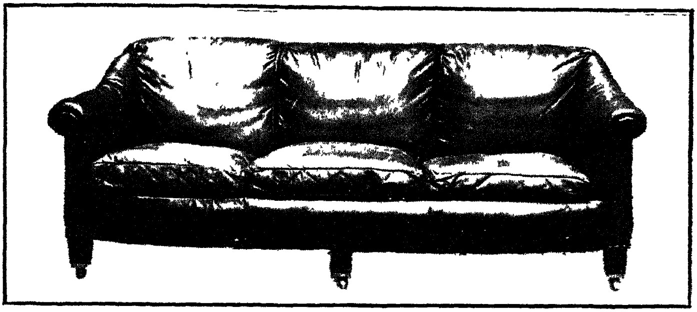


A lead bullet (Minié ball) of the Civil War, found in an oak log traversed by the burrow of an oak-boring insect. (Redrawn from "Field and Forest.")

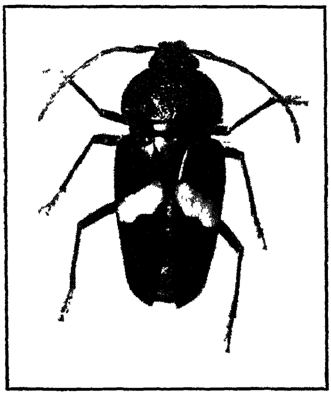
the timbers of houses, that they are a serious menace where telephone and telegraph poles are concerned, and that they do much damage of other kinds. We know that in Washington, D. C., they have invaded the Capitol building, and that they bored under the Senate Document Room and fed upon such precious papers as Jefferson's Manual on the Constitution and the Rules of the House of Representatives. Moreover, the Bureau of Engraving and Printing, said to be the largest and best-equipped printing plant in the world, has suffered greatly. The little pests have eaten postage-stamps, dollar bills, and special Liberty Bond paper.

The National Museum, the Congressional Library, the Bureau of Standards, and all the temporary federal structures still standing in Washington as reminders of the World War, have been visited by the unseen but voracious pests. They are found in decaying stumps, fence posts, boards everywhere. They are especially found in flooring and furniture above boilers or furnaces where the temperature is high and the wood is moistened by hot steam. Factories, granaries, barns, greenhouses, sheds, outhouses, and all other wooden structures are attacked.

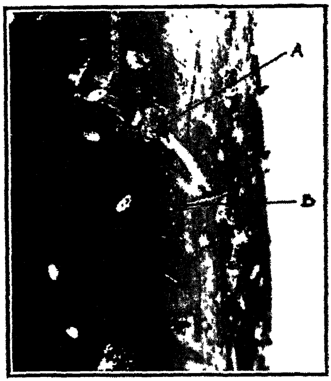
These insects have been found in graveyards, eating the pine boxes and coffins of the dead, and extensive damage to skulls and bones generally by termites has been noticed in graves in Egypt and Nubia. Electrotype blocks and other wood products, books in libraries or elsewhere, pamphlets, paper documents and plans, wood-pulp products, rolls of cloth and other fabrics, clothing, shoes, and other leather articles, as well as food stored in dark and damp basements or similar moist places where the ventilation is poor, are sometimes seriously injured. Cotton



Upholstered couch harboring thousands of adult carpet-beetles which were found emerging and spreading about the house. Superficially, no sign of infestation. (After Back, U. S. Dept. Agriculture.)



Adult of the lead-cable borer of Brazil—*Megaderus stigma*. Enlarged about one and a half to two times. (After Snyder.)



A section of lead cable affected by the lead-cable borer of Brazil, showing borings at *A;* and the shell left by the larva after issuing at *A* and *B*. (After Snyder.)

yarn and cotton goods, bandage muslin, stored rice, sacks of flour, have been damaged by them; and they have been known to attack a great variety of living trees, bushes, and shrubs. Even field crops are not safe from their inroads. Sugar-cane, cranberry bushes, and young squash plants have suffered. The ordinary potatoes and sweet potatoes, as well as corn plants, have been eaten by them. And injury to vineyards has been noted in Algeria, France, and North America.

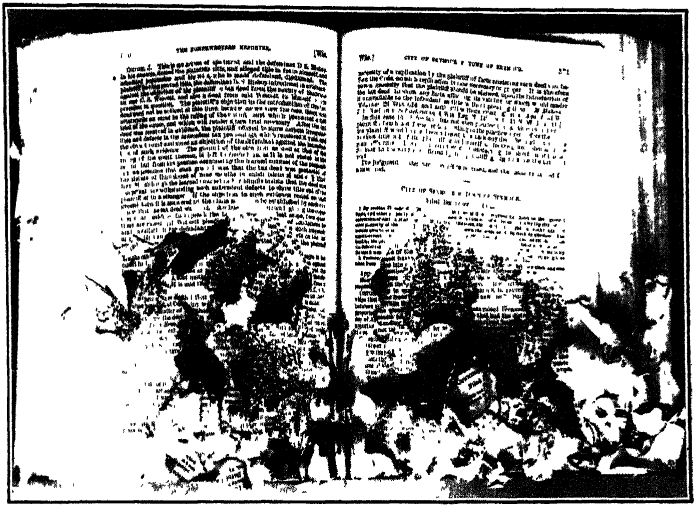
It is useless to extend this category further. One most extraordinary thing about the diet of termites is that the younger individuals are fed largely on the excreta of the older ones, either from the surfaces of their bodies or from their anal extremities. It has been found that, as Snodgrass puts it, "Each individual, therefore, is a triple source of nourishment to his fellows—he has to offer exudates from the skin, crop food from the mouth, and intestinal food from the anus—and this mutual exchange of food appears to form the basis for much of the attachment that exists among the members of the colony." He goes on to say, "The golden rule of the termite colony is 'Feed others as you would be fed by them.'"

It has been found that both protozoa and bacteria occur normally in the intestines of all termites except the higher forms. There are Spirochætes, Amœbas, and Flagellates. No one has been able to find out what the relation of the Spirochætes is to the termites. Apparently they do not benefit the termites, but the Amœbas and the Flagellates seem to contain enzymes that digest cellulose. We have seen that cellulose is the principal food of termites, and they get it from all sorts of vegetation. As Dr. T. E. Snyder has said:

> These soft-bodied termites, whose bodies are full of juices, must have a wonderful chemical laboratory in their bodies, or they could not live in very dry wood, or without the element nitrogen. It must be that they directly or indirectly through their intestinal low plant and animal parasites manufacture water from the air and cellulose, as well as fix atmospheric nitrogen into forms available to them as food,—for animals must have nitrogen in order to live. Termites can not obtain nitrogen from their normal food which is derived entirely from vegetation.

Not all termites, however, have these helpful protozoa in their intestines. The higher termites (Termes-Group), that build mound nests in Africa and the Orient, cultivate mushrooms for food in special fungus gardens, and so obtain their cellulose indirectly; it is digested for them by these low forms of plant life.[1]

[1] "Friends and Foes of Termites or White Ants," in the "Zoologischen Anzeiger," 1929.



Book damaged by termites (*Reticulitermes flavipes,* Kol.), from a library at Van Buren, Arkansas. (After T. E. Snyder. Courtesy U. S. Dept. Agriculture.)

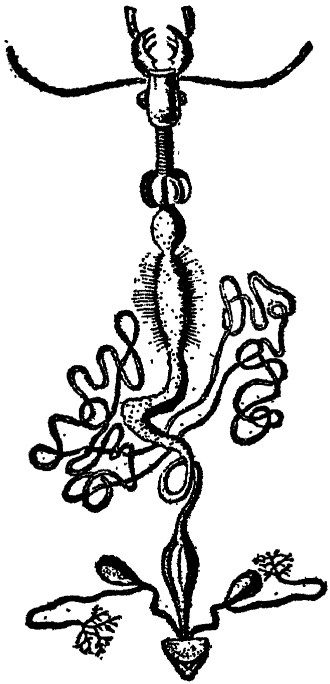
A queen termite from a tree nest in Panama.
(Courtesy T. E. Snyder.)

Termites, because of their elaborate communities and differentiation into castes, are among the most interesting of all the insects, and probably show a higher social organization than any other animals now living, not even excepting the true ants and the bees.

The thought has been advanced that by the invention of new foods the waste caused by insects may in a way be obviated; and much has been said about the synthetic food products that are now being developed by the chemist and the biologist and that will be developed more rapidly in the future. There is also much talk of the utilization of foods that now exist and are little used, and about the food that can be raised on waste lands and that which can be gained from the ocean. Predictions are made that food in the future will be obtained from the light of the sun and the nitrogen of the air. Dr. Lipman said not so long ago that synthetic chemistry may assume responsibility for the manufacture of alcohols or even carbohydrates in the factory rather than on the farm. Dr. Barnard, President of the American Institute of Baking in Chicago, is reported to have said that thirty men in a factory the size of a city square can produce, in the form of yeast, as much food value as one thousand men working on seventy-five thousand acres under ordinary agricultural conditions.

I am mentioning these matters here, under the head of the diet of insects, because, from what we have just seen regarding the variety of things that the little creatures can eat and upon which they will flourish, we may reasonably assume that any food that might be invented would be subject to insect attack, at least when in storage.

It is fair to state that only in comparatively recent years have we begun to make a determined effort to understand the physiology of insects. There can be little doubt that they have physiological advantages over the higher vertebrates that may be as pronounced as the anatomical advantages we have already pointed out. Fundamental researches in this direction are now being carried on in several countries. Their structure is so different from that of the vertebrates that their physiology must differ radically. And upon their physiology, as much as upon their structure, must their behavior depend. When we think that after scores of years of work by brilliant men our knowledge of the physiology of the human species still has many gaps, we begin to appreciate the task to be performed before we begin to understand the physiology of insects. To understand their behavior, we must understand their physiology. At present insect physiology is the largest and the most important of the comparatively unexplored fields. Fortunately, just now several well-trained young men are devoting their attention to it.



Alimentary canal of a ground-beetle, and some of its appendages. (After L. Dufour.)

It is certain, however, that the relations that exist with the insects between the vital functions of circulation and respiration have been of enormous aid in their success as a type of life. Not only does the blood penetrate to every part of the body quite as effectively as with us, but the air which purifies the blood also penetrates to every part of the body, purifying the blood everywhere, instead of being confined to the lungs as in the so-called higher animals.[2]

We have recently in-

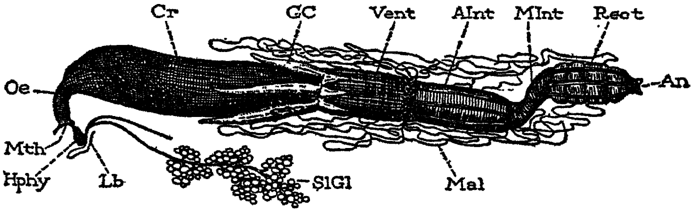
[2] Dr. David Sharp, after asking the question how it has come about that such insignificant creatures have been so successful, offers this opinion: "It is possible that the answer will be found in the peculiar relations that exist in insects between the great functions of circulation and respiration; these being of such a nature that the nutrition of the organs of the body can be carried on very rapidly and very efficiently so long as a certain bulk is not exceeded."

vented predigested foods for human beings, but this predigestion of food before eating has been carried on by certain insects presumably for ages. There are some ground-beetles, for example, that pour saliva (or possibly gastric juice) over their food before they eat it, so that digestion is finished before it is eaten and assimilation begins immediately after the food is swallowed. A large number of insects, both among those that bite and those that suck, possess this power of preventing indigestion and the consequent impairment of their stomachs.[3]

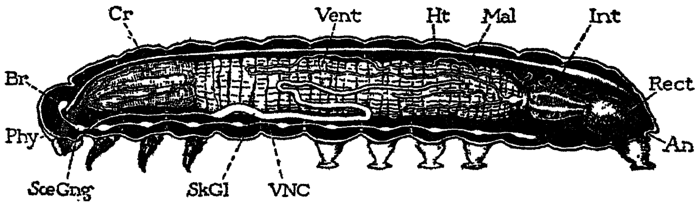
When insects are born they are at once capable of taking care of themselves. There is no long period of helpless infancy when they must be cared for and watched over; when they are exposed to all sorts of dangers they take care of themselves, and they are hatched from eggs which are so placed by the mother as to help them in this self-care.

[3] The larvæ of some of the water-beetles (genus Dytiscus) which sometimes eat even small fish, have no mouths, but their long curved jaws are hollow, and the larva sticks these mandibles into the body of its victim and sucks the juices. It is noticeable that it is able completely to empty the body, which at first is composed of solid flesh; it does this by injecting through its jaws into the body a digestive fluid which converts the flesh and all of the internal organs into a liquid that can be sucked up. Such external digestion occurs also with the larva of the ant-lion; and even wood-boring caterpillars give out from their mouths a fluid that partly digests the wood upon which they feed, thus enabling them to make their burrows in solid tree trunks without difficulty. It seems to be true, further, that plant-lice, through their beaks, inject a digestive substance rich in diastase into plant tissue, which softens it and changes its chemical nature before it is sucked up.

There is no old age with insects. When their work is done they die; and this holds just as well for those wonderful social insects like the bees and the ants, the efficiency of whose colonies has been pointed out by scores of writers and which



Alimentary canal of a grasshopper. (After Snodgrass.)



Alimentary canal of a caterpillar. (After Snodgrass.)

have been held to be models for study and emulation by the human species, as it does for the free-living and solitary species. The insect apparently dies before its faculties or its structure have begun to degenerate. It has no bones to grow brittle with age; the chitin of which its outer skeleton is formed seems, on the contrary, to grow stronger with age.

We hardly realize, until we make this comparison, what an enormous handicap is the absolute dependency of the immature for many years, and the almost equally absolute dependency of the aged, also for many years, with the human species. Dr. Phillips has pointed out that the fact that field-worker bees live mainly if not wholly on a carbohydrate (sugar) and no protein, probably explains why the duration of life in workers is determined by the amount of work they do. In this case, he says, the specialized food habits have changed the whole metabolism and the result is a decrease in longevity. To compensate for this, excessive brood-rearing is necessary to keep up the numbers.

Insects digest their food with great rapidity. The larger leaf-feeding caterpillars eat enormously and most voraciously, and void their excrement at short intervals. In a forest infested by the gipsy-moth the sound of the dropping of the excremental pellets on the ground, strewn as it is with dead leaves, resembles that of rain in a summer shower. The domestic silkworm as it approaches full growth eats so many mulberry leaves that the services of many children are needed to supply the wants of a family's crop of silkworms, say in northern Italy. This silkworm of commerce has been studied for scores of years by competent scientific men in

Europe. They tell us that when the silkworm is just about full-grown it will consume rather more than its weight of mulberry leaves each day. Imagine a man—me, for example—eating one hundred and sixty-four pounds of oatmeal porridge each day, and you will have a fair comparison!

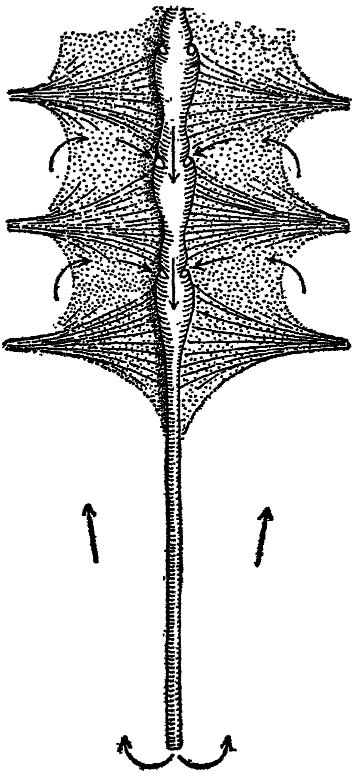
And some of the carnivorous forms digest their food almost as rapidly. There seems, for example, almost no limit to the voracity of the dragon-fly. Beutenmuller tells us, in his Lamborn Prize essay, that he has seen one of them (*Æschna heros,* a large species) eat forty house-flies in two hours, while another species (*Libellula pulchella*) he has seen devour twenty-five flies in the same period.

The name *enzymes* has been applied to the substances that hasten digestion, and while the enzymes that have been found in the few analyses that have been made of the digestive fluids of insects seem to be the same as those found with the higher animals, the insects surely seem to digest their food with infinitely greater rapidity. This rapidity, however, seems, so far as we yet know, to be the insects' only advantage in the actual process of digestion.

A very interesting point connected with digestion was told me by Dr. E. F. Phillips, a great authority on the honey-bee. Speaking of the thoracic glands, so useful in digestion, he says that with the honey-bee they are changed in function by furnishing a digestive ferment, or enzyme, which predigests the nectar. The result is that honey, consisting of invert sugar, instead of chiefly cane sugar, does not crystallize in the comb.

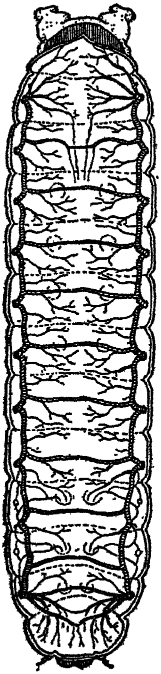
In fact, there has been much more activity in the investigation of the problems concerning insect nutrition and metabolism than is realized even by the people engaged in work with insects. This is evidenced by a long paper by B. P. Uvarov, of the British Museum of Natural History, that covers 90 pages of the "Transactions of the Entomological Society of London." The bibliography alone covers 22 closely printed royal-octavo pages. Brief abstracts of these papers, in typewritten form, were donated to the United States Bureau of Entomology by the Empire Marketing Board. They cover 592 sheets.

When it comes to the distribution of the digested food, insects have enormous advantage over the vertebrate animals. With us, such food goes into the lymphatic vessels and thus to the blood, by which it is carried in arteries and arterioles and capillaries to all parts of the body. With the insects, however, the digested food goes through the alimentary walls directly into the body cavity, and this whole cavity is full of what we call the blood of the insect. This so-called blood is colorless or slightly yellow, and is in reality lymph. It is kept in motion by what answers for a heart with insects, which is a slender tube running along the mid-line of the back, having apertures at the side and an opening at its front end into the body cavity. It has muscular attachments that cause it to pulsate, and the blood is drawn in through openings in its side and is thrown out in front. Thus there is a sort of circulation, and the digested food is dissolved in the liquid and carried all through the body. As it comes in contact with the body cells, these cells take from it what they need. Thus the whole process is far simpler than that of warm-blooded animals.



The heart of an insect. (From Snodgrass. Courtesy U. S. Dept. Agriculture.)

And now as to respiration. Air-tubes (tracheæ) run through the whole body. There is a main trunk along each side, opening by a spiracle at each side of each body segment. Each spiracle is guarded by a valve operated by suitable muscles so that the opening can be closed. The main trunks along the two sides of the body send off branches which ramify and penetrate all tissues. The smallest ones (tracheoles) are so delicate that the oxygen of the air passes freely through their membrane and purifies the so-called blood. Thus the whole body is virtually a lung. The openings of the spiracles not only admit the oxygen-filled air-current from the outside, but also allow expired air to enter the atmosphere.



Respiratory system of a caterpillar. (From Snodgrass. Courtesy U. S. Dept. Agriculture.)

The tracheal system in most insects, especially those that do not fly or that fly only occasionally, is simply a system of branched tubes, but in many of the very active species that fly continuously and strongly the main trunks or branches of the tracheæ develop into round or oval sacs. Bees, grasshoppers, dragonflies, some true flies, May-beetles, and certain other insects have very extensive air-sacs. These undoubtedly serve as reservoirs of air from which the finer branches of the tracheoles may be replenished. These air-sacs help to account for the extreme lightness of many rather large insects. That they appreciably alter the specific gravity of these insects and assist much in flight, however, is doubtful. Undoubtedly they increase slightly the volume of the body, but the temperature of the air within the sacs is not much higher than that of the atmosphere, and of course the increased size of the body brings about a greater resistance to the air during flight. The muscular activity used in flying must necessitate an abundant air supply and more rapid breathing. These sacs, then, act as quickly filled storage reservoirs closely associated with the muscles.

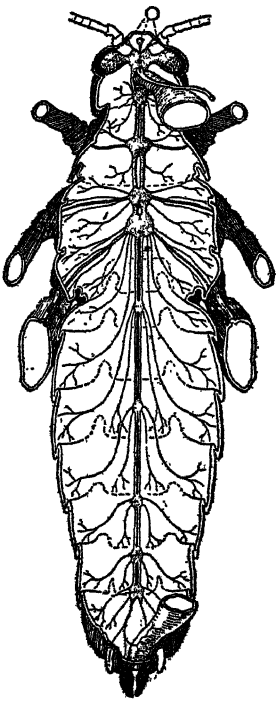
Many insects live under water, and some adult insects, like water-beetles and water-bugs, frequently dive and swim under water. Certain ones carry down with them supplies of air, either beneath their forewings or as bubbles about some part of the body and with access to the spiracles. Others have only their hinder spiracles open, and these are placed upon some protuberance that can be thrust through the surface film of the water so as to reach the air, as is the case with the mosquitoes, for example.

In other aquatic insect larvæ there are gills of different kinds—all, however, external—in place of the spiracles. These gills are extremely delicate, and the oxygen enters through their membrane to supply the tracheoles that fill them. They are called tracheal gills. In some delicate aquatic larvæ oxygen enters the tracheoles from the water through the whole body surface and there are no specialized air-gills—an interesting example of economy in machinery!

It must be said, however, that insects have very slight oxygen requirements as compared with warm-blooded animals. Dr. F. E. Lutz has made some ingeniously contrived experiments rather recently in which he has shown that insects may survive with the oxygen reduced to an almost infinitesimal amount. Their small size would lead us rather to expect this, but their intense activity would negative the expectation somewhat.

It is the general impression that insects are very cold-blooded, but it appears that there is a fairly high body temperature produced by the combustion processes that are going on constantly in the tissues. The summer temperature of a beehive is said to be over 90° Fahrenheit, and the winter temperature, strange to relate, is nearly 80° Fahrenheit. I remember that once I was handed a paper bag full of beans. It was a comparatively cool day, but the bag was hot. On opening it I found that the beans were very badly infested with Bruchus, every seed containing several of the little larvæ or of the beetles themselves. The obvious temperature in this case, however, was not due so much to the massing together of the insects as it probably was to the constant friction of their jaws.

The elimination of waste products is performed in the insect's body. Instead of possessing kidneys, the insect has a set of tubes running through the body cavity (malpighian tubules). The nitrogenous waste matter, discharged by the cells into the blood, is taken out of the blood by the cells of these two tubes and carried to the alimentary canal below the stomach, and is thus discharged from the body with the food waste.



The nervous system of a grasshopper. (From Snodgrass. Courtesy U. S. Dept. Agriculture.)

There is a marked difference in the development of the nervous system of insects and the whole Arthropod series as opposed to the development of the same system with the vertebrates. With the vertebrates there has come the dorsal hollow tubular system with its greatly enlarged brain allowing for a type of mental activity not known in the Arthropod series. With the insects there is a long chain of ganglia extending through the ventral part of the body instead of the dorsal, virtually one ganglion for each segment, and from these branch nerves which ramify through the body and to a certain extent the limbs. In the less specialized animals of both the Arthropod and the vertebrate series, reactions occur through certain reflex actions of the entire organism, usually called tropisms. These tropisms grow into what we call instinctive reactions, and this is as far as they go with the insects. With the vertebrate series, with man at its head, reasoning power comes in, added to instinctive behavior. Thus it appears that possibly in the nervous system alone has man the advantage over insects.

We might as well consider briefly under this head of physiology the question of the resistant powers of insects to extremes of temperature. There is little doubt that temperature is the principal element in the control of the geographic distribution of a number of species, but there are certain cosmopolitan forms that seem to thrive in almost every climate, and these accommodate themselves readily to temperatures that could not be endured by other types. It is true that the majority of forms, however, are limited to certain climatic zones to which they have become adapted through centuries.

And yet many of these forms are constantly encroaching on other zones as opportunity offers, and the rapid adaptability of certain species to new temperature conditions is surprising. For example, when the cotton boll-weevil first entered Texas and reached the region where it encountered an early and severe frost it was annihilated, but in less than ten years the waves of weevils coming from the South had become so modified physiologically that they endured the cold to a great extent; and now they pass the winter successfully at the northern limits of the cotton-belt. Many insects endure extremes of cold and heat that would be fatal to warm-blooded animals. Others, however, are easily affected by extremes. Once in Washington, D. C., there was a summer when almost every shade-tree was covered with plant-lice. One day in July, bright and sunny, the temperature reached 106°. Virtually every aphid was killed within a few hours.

Not only many adult insects but also many larval insects survive severe winters, remaining apparently frozen and absolutely inactive. And of course in the egg stage and the pupal stage many others pass through severe winters. Possibly the extreme instance so far found of endurance to cold, and not only endurance to but preference for cold, was a primitive Orthopteron insect found by Dr. E. M. Walker, of the University of Toronto, on Sulphur Mountain at Banff, Alberta, in 1913. Dr. Walker and his associate, Dr. Norma Ford, found that this insect normally lives at a temperature about zero Centigrade. Early attempts to keep it alive in the laboratory were not successful, but Miss Ford finally succeeded by keeping it in a jar continually packed with ice, in partial darkness, and with each insect living in a separate jar with damp moss.

In a long series of experiments Miss Ford found that the insect died at a temperature a few degree above zero and that it would support a temperature of more than four degrees below. It was active at zero, and apparently the species was normally accustomed to that temperature. It feeds to some slight extent upon the bark of mosses, but apparently normally upon other insects that are chilled and disabled by the cold. It is a well-known fact that many insects which live normally at a greatly higher temperature migrate over or upon mountains where they are chilled by the cold and perish; and the bodies of these, or at least of the ones which are soft enough to be punctured by the jaws of the Grylloblatta, form the food of the cold-loving creatures.

Conversely, many insects support high temperatures, and some aquatic forms have come to inhabit thermal springs. C. T. Brues, who has made a study of animal life in hot springs,[4] has shown that there are water-beetles and water-bugs that live normally in water of the temperature of 113° to 115° Fahrenheit, while certain larval midges were abundant in the mud of a shallow hot pool in Yellowstone Park at a temperature of 120° Fahrenheit. He also points out that an earlier observer (Owen) found similar larvæ in a Californian hot spring of a temperature of 124° Fahrenheit.

In the opening paragraph of this section we have referred to physiology as the most important of the comparatively unexplored fields in entomology, but, while its importance is no less, it is fast being explored. In the past ten years, according to the "Zoölogical Record," 706 papers on this subject have been published; and

[4] "Quarterly Review of Biology," Vol. II, No. 2 (June, 1927), pp. 181–203.

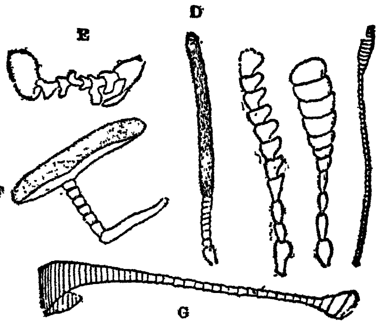
the time has come, apparently, for the publication of a comprehensive work that will bring our knowledge down to date. It is true that Comstock, in his "Introduction to Entomology" (1924), devoted rather more than two hundred pages to a consideration of the structure and metamorphoses of insects, in which he gives lengthy consideration to the anatomy of all functioning organs. Also the Englishman Imms, in his "Textbook of Entomology" (1930 edition), gives nearly two hundred of his royal-octavo pages and a wealth of illustrations to the internal anatomy and physiology of insects. But it all seems so technical to the non-scientific reader, and such a person must feel that the physiological facts displayed can be interpreted only by one learned in the physiology of warm-blooded animals. At least neither author makes any comparative comments, and that is what we need.

What are apparently sound and very informative articles are published constantly by industrious and intelligent young workers. For example, I noticed in the August 1, 1930, number of the "Journal of Agricultural Research" what is obviously an important article on the "Anatomy and Physiology of the Digestive Tract of the Japanese Beetle," by M. C. Swingle of the United States Bureau of Entomology. He writes learnedly of the digestive enzymes and of maltose and sucrose and monosaccharides and tryptase and peptase, but those are words that have little meaning to one who is not a physiological chemist.

The very latest book to consider rather comprehensively the most recent advances in physiology of insects is entitled "Recent Advances in Entomology," by A. D. Imms, published in 1931 by P. Blakiston's Son & Co., of Philadelphia. There will be found two chapters on the sense organs and reflex behavior; and, in four chapters on ecology, questions of temperature, humidity, light, atmospheric pressure, food, and so on, are taken up.

We cannot make the same broad generalization about the superiority of insects in speaking of their senses that we can in regard to their anatomical structure. There is little doubt that we see better than insects do; but, on the other hand, there is no doubt at all that our olfactory sense is greatly inferior to theirs. A great many papers have been published about the senses of insects and most careful histological work has been done by a number of European authors and by some American workers on the supposed sense organs—the majority of them in comparatively recent years and since the development of histological technique in modern laboratories.

While our sight is better than theirs, and while their olfactory senses are much better than ours, we are more or less in doubt about the other



Antennæ of different insects. (After Berlese.)

Branched antennæ of different insects. (After Berlese.)

senses. The trouble is that we can only compare the minute structure of certain organs with similar structures found in the human body. We know that in mammals these structures mean one thing and we assume that they mean the same thing in insects. There seems no doubt that insects hear, but their auditory apparatus is situated in a different part of the body. Their sense of touch, their tactile sense, is very delicate, and in nearly all species so-called tactile hairs have been developed, especially on the antennæ. These function probably to a degree that must be left largely to the imagination.

The eyes are radically different from ours, and the sight therefore must be of a different character. The principal eyes are compound, sometimes of very large size, and have very many facets, and through these facets they must have what is called a mosaic vision. No one knows exactly how much they can see through their eyes, which cannot be moved, cannot be closed, and apparently cannot be focused upon objects at various distances. It is said that the compound eye detects movements readily, but I think that that is more or less theoretical.

Then there are often three or more simple eyes. To these eyes most objects must be out of focus, and they see things only at one definite distance. The focal distance is short, because the lenses are very convex, and it may be that they simply distinguish light from shade.

Many insects are blind or almost blind; some apparently have no eyes at all. And strange things sometimes happen following a metamorphosis. The adult male of certain scale-insects, for example, loses its mouth parts and these are replaced by pigment spots that were once supposed to be rudimentary eyes. As to the inability of the insect eye to catch details or indeed to perceive much more than motion and light and shade, I remember that S. H. Scudder once told me (perhaps he printed it somewhere) that, lying in his tent one afternoon on a plains expedition, he saw a fly-killing wasp attempt repeatedly to capture the shadow of a fly on the tent wall, the fly itself being on the outer side of the canvas. On the other hand, one of my colleagues (not an entomologist) tells me that he is sure that house-flies have extremely good sight, since when he rises from his chair to get the fly-swatter they see it and know what it means and disappear!

When it comes to the perception of odors, it is impossible not to believe that insects detect odors that we cannot perceive. This particular subject has been studied with great care by a number of trained observers. Dr. N. E. McIndoo has paid especial attention to the olfactory sense of insects and has published a number of important papers. He has found microscopic organs that he calls olfactory pores. These olfactory pores, according to him, are widely scattered over the body, head, and appendages of insects. The more highly developed the insect, the more the pores are arranged in groups, most of the groups being found on the legs, wings, and mouth parts.

In some of his late work this writer has constructed what he calls an "insect olfactometer," and by means of it has tested the odor sense of many insects. He has found indisputable proof for the first time that plants attract insects by emitting odors. The delicacy of the detection seems beyond our appreciation. The female is guided by this sense to the proper place to lay her eggs, and the males seem undoubtedly to be attracted by it to the females, even from long distances. When we consider that males are so attracted for literally miles, it seems almost uncanny—or it did seem so to us before such marvelous discoveries were made concerning electric waves, facts which of course we should once have considered impossible.

In some way or another insects have an extraordinary recognition of localities, and the social species have remarkable ability in finding their homes after long journeys. The homing of pigeons is undoubtedly facilitated by keen eyesight, but the homing of bees and wasps must be something different. It may be that they recognize landmarks, and perhaps their keen appreciation of odor is the controlling factor. Forel has called it a topochemical sense. *Topo-*

chemical is a good word, but the expression means very little to us. It may come about in some mysterious way unknown to us and not even guessed at by the many ingenious writers who have been looking into the subject. It seems, however, that we can very largely rule out sight in this homing.

As to the organs of hearing, here again there is a radical difference from the higher animals. For example, highly specialized ears are found in grasshoppers on each side of the first abdominal segment. Crickets and katydids possess similar ears, but with these they are on each front leg, near the base of the tibia. And male mosquitoes are supposed to hear through the antennæ.

The probabilities are that insects perceive differences in temperature readily, and that they are extremely sensitive to changes in humidity. McIndoo has pointed out that bees can always tell when a thunder-shower is approaching.

This question of temperature perception has, in fact, been studied very carefully with the honey-bee. The winter cluster is formed at 57° Fahrenheit, and in some way the bees know when it gets this cold. Dr. E. F. Phillips has written me:

> This may be merely due to the effect of chilling of a cold-blooded animal comparable to the muscle sense

and I have suspected that below 57° (F.) all insects become increasingly unable to use their muscles which finally culminates in hibernation. Bees can walk at temperatures too low for flight. This action at a specific degree of temperature may be called an "absolute temperature sense," comparable to an appreciation of absolute pitch, but whether it is due to the function of temperature-sense organs, so far unidentified, or merely to the physiological condition of the muscles remains to be determined.

While the subject of the senses of insects is an important one, the difficulties in the way of investigation are enormous, and the uncertainties that must exist, even after the most arduous study, are extremely discouraging. It has become an exceedingly technical study, and one has only to glance over the pages in the chapter on sense organs in Dr. Imms's general text-book to realize the extent of the problems and the insuperable difficulties in the way of their real solution.

There is nevertheless a whole field of interesting reading connected with the subject, as any one who has read Fabre or Bouvier's "Psychic Life of Insects" or Forel's fascinating work "The Social Work of the Ants" may realize. There is no doubt that insects have certain extremely delicate powers of perception which are still mysterious in various ways.

It is unquestionably true that if the human species is to control the insects it will be on account of our possession of the characteristic known as intelligence. This opens up the question of the difference between intelligence and instinct. It is astonishing what a wide difference of opinion has existed among naturalists on this point. There has been what may be termed a "school" of observers who attribute not only to the birds and the lower mammals but also to the insects, especially to the social insects, some of the psychic attributes of the human species. This school has been termed the anthropomorphic, or, better, anthropocentric school. Its writers were very much in evidence in the United States during the early part of the present century, and most of them have been utterly unscientific. I never talked on this subject with Colonel Roosevelt, but, remembering his caustic criticisms of one of the writers of this class, I feel sure that he was soundly scientific in his own opinions.

As good a naturalist as John Burroughs, despite his love for the birds and other wild creatures, would never admit that they think as we think; and I remember he told me once that only when an individual animal encounters a situation entirely new to the history of its race and surmounts it by its own ingenuity can it be said to think. I countered by telling him of my observations on certain ants in one of the greenhouses on the Department of Agriculture grounds at Washington. There were Liberian coffee trees in the greenhouse, and these coffee trees have nectar glands at the bases of some of the leaf-ribs. There were ants in this greenhouse, and none of that especial species had ever seen a Liberian coffee tree. They found the nectar glands, however, and immediately proceeded to enlarge them by gnawing around the edges until they made large shallow pits. This was not done, apparently, to obtain increased nectar for their own food, but to place in these pits mealy-bugs, collected from other plants, which in such advantageous situations increased and grew more rapidly, the ants themselves being especially fond of the excretions of these mealy-bugs. I forget Burroughs's comment on this story; I am not sure that he believed it.

Nearly thirty years ago, when nature study was very popular in the United States, I was asked to write a book on insects which should interest people by injecting into the lives of insects a kind of intelligence akin to that of human beings. This would have been pure anthropocentrism, and I declined to do anything so unscientific, and wrote instead "The Insect Book" the sales of which have proved a disappointment to its publishers, although I tried to make it as popular as I could with strict regard to scientific accuracy.

Sir John Lubbock (afterward Lord Avebury) was the leading entomologist who saw a real intelligence in insects. In the introduction to his charming book on bees, ants, and wasps, he says:

> The anthropoid apes no doubt approach nearer to man in bodily structure than do any other animals; but when we consider the habits of Ants, their social organization, their large communities, and elaborate habitations; their roadways, their possession of domestic animals and even, in some cases, of slaves, it must be admitted that they have a fair claim to rank next to man in the scale of intelligence.

The opposing school of biologists who looked upon the marvelous acts of insects as mechanical reflexes entirely devoid of psychism is well represented by the German Bethe, of Strasburg, who after a long and careful study of ants and bees decided that they lead a purely reflex life and perform simply as machines all of the acts that seem so intelligent.

But we are not obliged to hold to either of these extreme views. Our embarrassment would be great if we were to hold to one school or the other. We must confine ourselves to observation and experiment, and let theorizing alone for a time. Certain acts are obviously the result of reflexes, such as the flying of moths to artificial lights—and this is a destructive reflex, since many of the little creatures are burned to death. Much lower organisms are attracted to or repelled by light; and, working up in the life scale from these lower forms, we find that from automatic and simple reflexes to simple stimuli like heat, moisture, gravity, and so on, we gradually come to a complication of reflexes, to a differential sensitiveness, to something that appears to be individual or associative memory, leading to what is called the species memory, and through spontaneous changes of habits which quickly become species habits, to an automatism that governs what we call instinct as opposed to intelligence.

It is a far cry indeed from the minute infusoria and their automatic movements in a basin of water warmed at one end, as studied by Jennings, to the seemingly intelligent actions of the different members of a colony of bees or of ants or of wasps or of termites, and yet we find existing in nature at the present time every grade between the simplest reactions of living matter and the extremely developed and complicated and efficient instincts of the highest social insects. Undoubtedly the existence of the infinite series of intergrades points out the course of the gradual evolution from the lowest end of the scale to the highest. One reason why the anthropocentrists have been unable or unwilling to differentiate between the actions of the highest social insects and the reasoning intelligent acts of human beings is because they have not studied the question from below upward, but rather downward from the standpoint of human intelligence.

All along the scale there have been, doubtless, individual advances that have become a part of the species evolution. A new advance becomes a part of the equipment of the species, but at no point with the insects has it developed into reasoning power. Each acquisition has helped toward what has been termed a species memory, and it is automatic in the individual.

The reactions of insects have been termed instinctive because they are automatic in a way and are a part of the equipment of the species; but it has been shown that the instincts have changed and are changing, and through the changes has come the evolution toward perfection; and during the countless ages of evolution the instincts of insects have developed to an amazing degree.

Very rarely do we find the beginnings of one of these changes due to the act of an individual. Williston, however, observed thirty-five years ago a wasp which had dug its burrow, filled it with food for its young, laid its egg, covered the orifice of the burrow, and then *used a tool,* since it picked up a bit of stone with its jaws and used it as a tamping iron to pound down the earth and smooth it over. The same observation has been made in two other cases—by the Peckhams in Wisconsin and by Pergande in Washington, D. C. This was the beginning, in all probability, of a race habit, and some day all the wasps of that species will instinctively use stones as tamping irons for their burrows; and yet down to the present it is apparently very exceptional and occurs only with a single species.

The only other recorded instance of the use of what may be termed a tool by insects seems to be found with certain ants of India and Brazil. These ants use their larvæ as glue-brushes, holding the larvæ between their jaws and gluing and fastening the leaves of which their nest is constructed edge to edge with the sticky secretion from the larval mouths. This is a more settled instinct. It has apparently become one of the effective methods of at least two species.

These two examples give us apparently two stages (although of a different nature) of the development of an automatic process. The use of a tool by the first wasp was intelligent because it broke the rule of a species habit; so also, probably, was the first use of a larva as a mucilage brush by an ant, but in the latter case it seems to have become an automatized habit of the species.

It is very difficult at this time to conceive all the steps in the building up of the absolutely perfect communistic societies of the social insects. This is especially true of the beginnings of the complex castes—the first sterilized worker, for example, and the division of the worker caste into its subdivisions, each subdivision consisting of individuals having their particular tasks, some of them highly specialized both in function and in structure, such as the soldiers of the termites and the so-called *nasuti* which have become peculiarly formed so as to act as plasterers in the termite nests. And then think of the development of the honey-ants, among which a certain caste of workers become simply winter storehouses for honey—or as I called them in "The Insect Book" animated pantries! Forel calls them "living bottles."

Human beings have not produced, and probably never will produce, such marvelously organized societies—so far as differentiation of labor is concerned and adaptation to particular kinds of labor—as we see among the insects. The societies are so marvelous, in fact, that the term super-organisms has been given to them. Bouvier has conceived the beautiful idea of a parallel between these communistic societies and such a group of differentiated cellular organisms as we see in the human body. Here the differentiated cells of the human body correspond to the neuters or workers of the insect society and, like them, function for the good of the organism and are sacrificed to preserve its life; the reproductive cells of the human body are represented by the royal individuals of the insect colonies and live, like them, with the active workers; and, like them also, these are immortal in the sense that they continue in their progeny.

However these marvelous instincts have developed, they seem never to possess a quality which can be given a higher intellectual rank than what Fabre calls discernment. Bergson, who has thought much on this subject, has written the following admirable lines which well apply to the very highest of the insects:

> Among animals, invention is never more than a variation on the theme of routine. Locked up within the habits of the species, the animal succeeds, no doubt, in broadening these by its individual initiative; but it escapes from automatism only for an instant, just long enough to create a new automatism; the gates of its prison close as soon as opened; dragging on its chain, it merely succeeds in lengthening it. With man, consciousness breaks the chain.

Bouvier, in "The Psychic Life of Insects," concludes with the following words: "These animals from the beginning were doomed to use organic tools, and they made the best use of them. Their main psychical task was to grave upon their memory and to repeat instinctively the acts to which these organs were fitted."

It is hardly to be wondered at that this question of instinct versus intelligence should have greatly occupied the attention of biologists, psychologists, and metaphysicians, for it is a fascinating field. It seems impossible that there should ever be any unanimity of views, for there are so many things to be considered. Perhaps the best definition of instinct is given by Wheeler in his remarkable book entitled "Ants." He says:

> An instinct is a more or less complicated activity manifested by an organism which is acting, first, as a whole rather than as a part; second, as the representative of the species rather than as an individual; third, without previous experience; and fourth, with an end or purpose of which it has no knowledge.

Bouvier, after writing the closing lines of his book which we have just quoted, apparently wrote (or added to) his introduction, and formulated the following admirable and significant sentences:

> We have a feeling that the psychic evolution of these animals is not less original than their structure, and that they are never so widely separated from us as when they appear to resemble us the most. The old anthropocentric school is indeed dead; we no longer attempt to explain the insects by man; we try to grasp the mechanism that allows the animal

to evolve mentally and to acquire activities which *seem* human.

In the epilogue in Volume II of Forel's wonderful work entitled "The Social World of the Ants" is a consideration of these questions, and in an appendix to the volume is "a study of the origin of instinct" by Ed Bugnion, based on his observations upon ants and termites. After indicating the origin of instincts and their heredity, his final conclusion is very well worth reading and belongs here:

The useful instincts, which are subject to the laws of natural selection just as much as the evolution of the organs, will persist, whereas the useless or harmful instincts will inevitably disappear.

While the life of the insect is dominated by instinctive activities which are usually unconscious, the life of man, apart from a few exceptional cases, is nearly always commanded by his conscience and his reason. The characteristic of the higher type of man is precisely to dominate his instincts and to fight them if they are bad.

Instinctive activity, as soon as it is fixed for any insect, varies very little; it is transmitted from one generation to another in practically the same form: hence the uniformity found in ants and termites with regard to the behavior peculiar to individuals of each caste.

But in strong contrast with insect communities, human societies are distinguished, from the bottom of the social ladder to the top, by the extraordinary diversity of the individuals composing it, and by a perfectibility which, despite the disappointments of the moment, justifies us in hoping for better times.

Is it not man's perfectibility which distinguishes him from the animal and is the *raison d'être* of humanity? And is it not this undeniable perfectibility which remains proof against the worst trials and enables human beings to create an ideal and to look forever upwards?

Almost every one who has watched living insects—especially if he has studied bees and wasps and ants—is inclined to discuss this subject of instinct and intelligence at length. Fascinating books appear from time to time which are quite likely to lead him into a mental fog if he does not sternly hold an open mind. E. G. Reinhard, in "The Witchery of Wasps," describes a series of careful and scientifically sound observations, and does it in charming language. And Major R. W. G. Hingston, in "Instinct and Intelligence," tells us of his long studies in India. Reinhard is content with the telling of his beautiful stories; but Hingston is more of a philosopher and is disposed to be argumentative. It is difficult to avoid his conclusion that certain insects have a memory and that they possess a rudimentary intelligence similar in kind to that of man. He admits that insect senses are in some ways more elaborate than our own, and, rather grudgingly, that there may be an unknown sense. But after all he thinks that the brain of man and the brain of the insect possess the same fundamental qualities, and goes on to say:

> They differ, however, immensely in degree, because they have evolved along diverging paths. The psychological tree has two great branches, the branch that represents the growth of intelligence and the branch that represents the growth of instinct. Man stands at the summit of his own branch and thus dominates all creation. But the insect crowns the other branch. In it instinct has reached the highest development. In fact, many acts performed by instinct are as wonderful as the acts of reason.

Maurice Maeterlinck, who had already written charming and philosophical books on bees and termites, has recently published a book under the title "La Vie des Fourmis." Maeterlinck besides being a poet, a delightful writer, and a philosopher, is very accurate in his scientific facts; and especially in this last book and the one on termites he has shown himself perfectly familiar with the writings of the most recent investigators. It was Maeterlinck, it will be remembered, who was largely responsible for the concentrating of the world's interest in J. H. Fabre, to bring about the Fabre jubilee before the death of the great writer, which resulted in impressive ceremonies, the striking of a beautiful medal, and the ultimate taking over of

Fabre's home at Serignan as a national preserve.

In his last work Maeterlinck carries his admiration of ants and their communities even farther than did former writers, or at all events he expresses his views in more beautiful and impressive language.

A clever anonymous writer in the well-known "Providence Journal" of November 24, 1930, has written about this book so interestingly that I must quote three of his paragraphs.

> The ant [he tells us] is incontestably one of the noblest, most courageous, most charitable, most devoted, most generous and most altruistic creatures on earth.
>
> Now we are prepared to believe almost anything the expert observers tell us about the marvelous instincts and perceptions of ants and their strange capacity for economic organization. We can admit their courage and their admirable devotion to community interests, but talk about the nobility and altruism of ants sort of strains our credulity. A good many of us have stood casually on the sidelines and watched ants behave, and what we have seen has convinced us that they are pretty cold-blooded creatures, however admirable their industrial virtues may be.
>
> Maeterlinck sees the ants developing in intelligence but says that we have nothing to fear from their intellectual progress because long before they can become a menace the human race will have ceased to exist. As to the ants' persistent will to live there

can be little doubt, and seeing that they were here in force millions of years before the first rudimentary man perhaps it may be assumed that they will survive the last and most highly developed man. But there is reason for skepticism as to the likelihood of ants gaining an increased intelligence. In that respect, some entomologists tell us, the ants of today are just about the same as their early ancestors of thirty million years ago. Whereas man, with only a million years behind him, is still gaining in intelligence, even if a good deal of the evidence we see about us does not seem convincing. Perhaps in time, another million years or so, he will become intelligent enough to triumph over the ants and all the other bugs.

Chapter IV

SOME OTHER IMPORTANT FACTS

ALTHOUGH hardly in line with our main argument, something should be said about the insects that live either during their whole lives or during part of their lives underground. They are extremely numerous.

Several investigators have counted the insects and other invertebrates to be found on four square feet or in other cases one square yard of soil, both of meadow land and of forest land, and on such a basis have computed the number of insects per acre. Among these writers is W. L. McAtee, of the United States Bureau of Biological Survey. Most of them have counted the insects *on* the soil as well as those *in* the soil, but Mr. H. M. Morris, formerly of the Rothamstead Station and now of Cyprus, while in England made a careful study of the creatures living actually in the soil to a depth of nine inches. One such study was made in permanent meadow land in Cheshire, and Mr. Morris estimated that the soil insects numbered well over three and a half million per acre. He found that in this locality the insects seldom penetrated to a depth of more than six inches, and that the great majority were found at a depth of not more than two.

The true underground insects are those that pass their entire lives beneath the surface of the earth—that are born there, that live and grow and die without seeing the light of day. Such, for example, are the true cave insects. There are a number of species of these creatures found in the great caverns in different parts of the world. Some of them feed upon vegetable mold and other low forms of plant life found in caves; others feed on dead animal matter, and still others feed on living insects. Nearly all are pale in color, and are blind or almost so, for they do not need eyes in the perpetual darkness. All of the so-called cave insects are supposed to be descendants of above-ground forms, which, through many generations of life in the darkness, have lost their color and their power of sight. The genealogy of these true cave species may be guessed at with some surety, for there are insects that are only partly changed in structure from above-ground forms to true cave species. Such are certain beetles that live in the catacombs of Paris, and other insects that have been found in the old and deep burrows of the Florida land tortoise.

Entirely aside from caves, rich loose soil always abounds with insects. These live upon the decaying vegetation (soil humus or vegetable mold) or upon one another. The most abundant are the little spring-tails or bristle-tails—diminutive creatures seldom more than a sixteenth of an inch in length. They frequently swarm in the ground in such numbers that the earth seems fairly alive. They are by no means confined to the surface of the soil, but have been found in great armies at a depth of six feet or more in stiff clay which they have penetrated by following the deeper rootlets of trees. Some of them have become so accustomed to the darkness that they have lost their eyes.

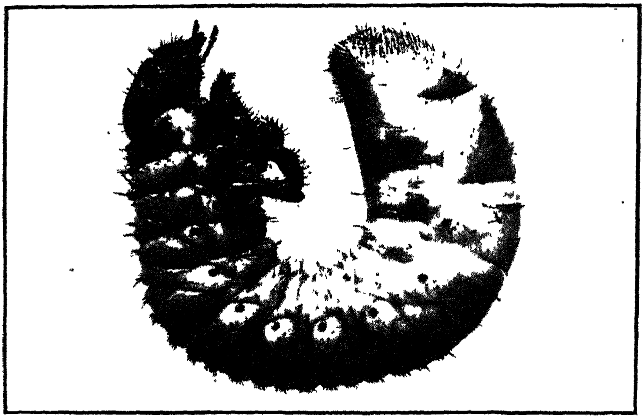
Other true underground insects are found in the nests of ants, where they fill many different functions. They have been grouped as follows:

(1) Species that are fed by the ants and from which the ants derive benefit by eating certain secretions of the insects.

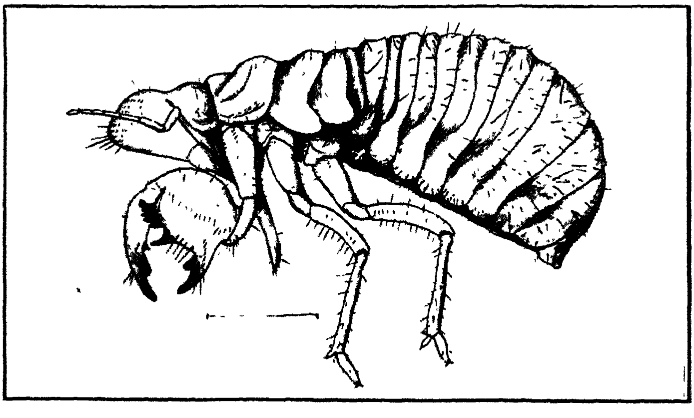
(2) Species treated with indifference by the ants, but which feed upon the bodies of dead ants and other animal and vegetable debris to be found in ants' nests. The ants do not appear to be hostile to these insects, and evidently gain some unknown benefit from their presence.

(3) Species that live among the ants for the purpose of killing and feeding upon them.

The first true ants'-nest insect was discovered



A common white grub—larva of Lachnosterna. (U. S. Dept. Agriculture.)



Larva of the seventeen-year locust, or periodical Cicada. Note the modification of the front legs for digging purposes. (After Marlatt, U. S. Dept. Agriculture.)

and studied not much more than a hundred years ago, but since that time a vast number of other species have been found, and a mere catalogue of their names fills a book of over two hundred pages. Such insects are called "Myrmecophilous" species, or ant-lovers. Father Erich Wasmann, a Jesuit priest living in Holland, has probably studied them more than any other writer. He has devoted many years to the work, and it has not been easy. If one digs into an ant-hill, the inhabitants are of course greatly alarmed, and there is much confusion. They are therefore usually studied in artificial nests in glass jars. Dr. Wheeler of Harvard has studied many of these strange creatures.

Although most of the ant-loving insects are strictly subterranean species, living their whole lives underground, the ants among which they live do most of their foraging above-ground, and thus may be considered types of a second group of underground insects, namely those that have their homes below the ground, for protection and concealment, but which live at least part of the time above-ground. But full information is readily available about the social habits of ants, their community life, the division of labor among them, their slave-making customs, their courage, apparent patriotism, and indefatigable industry. Wheeler's big book, for example, "Ants, Their

Structure, Development and Behavior," should be read—in fact has been very generally read.

There is an interesting class of underground insects that in their early stages hide in especially dug pits and lie in wait for their prey, but which when full-grown live above-ground. Such are the ant-lions and the tiger-beetles. Certain of these have been written about recently by Dr. W. M. Wheeler in an intensely interesting book called "Demons of the Dust."

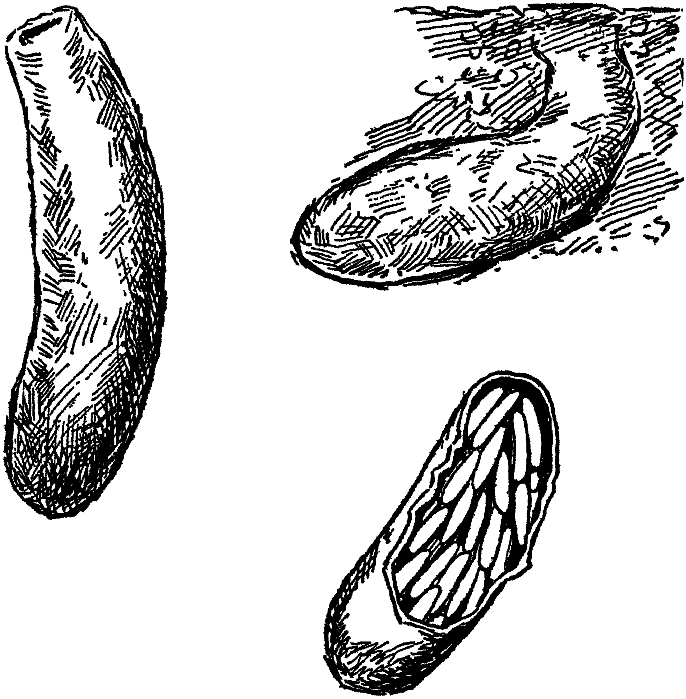
There are also numerous insects that live below-ground when young and become flying creatures above when full-grown, and that do not have the carnivorous tastes of the ant-lions and the tiger-beetles. Many of these species live in the larval condition on the roots of plants, and others on the so-called vegetable mold of rich soils. The large white grubs so often found in the soil of grass-lands belong to this class. They are the larvæ of several kinds of clumsy beetles known as Scarabs (May-beetles, or, in the Northern States, June-bugs).

The larvæ of the common brown May-beetles are root-feeders, living principally upon grass roots, and are sometimes so abundant and destructive as to destroy valuable lawns and the putting-greens of golf-courses. The now famous Japanese beetle belongs to this group. The larvæ of the beautiful green beetles known in the

South as "fig-eaters" also belong here. The wire-worms, which are the young of the click-beetles, or snapping-bugs, feed upon the roots of plants. And there are plant-lice that live underground and suck the sap from plant roots, like the famous grape-vine Phylloxera. There are also caterpillars which live almost entirely underground and feed upon living roots. There are maggots that have the same habit, and even scale insects. One of the most extraordinary forms of bark-lice, like oyster pearls in appearance, live underground and are the so-called "ground pearls" of the West Indies. They are often worn as necklaces.

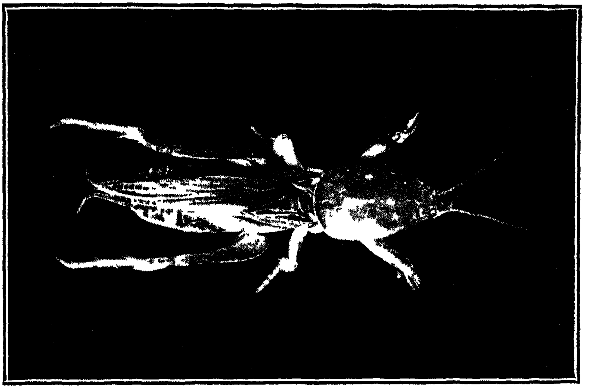
In addition, many insects living above-ground all their lives hide their eggs underground. Most grasshoppers, for example, do this; and many of the closely related crickets not only hide their eggs in this way but live underground themselves in the daytime, coming forth at night to feed or to collect grass leaves which they carry into their burrows and eat at leisure. There are other insects that hide below-ground during the day and feed only at night. Full-grown May-beetles do this, and the cutworms also. Cutworms are soft-bodied caterpillars and are so greedily eaten by birds and carnivorous insects that they must conceal themselves as much as possible.

Still other caterpillars, while living above-ground and feeding upon the leaves of plants, instead of spinning cocoons for their protection when they transform to the helpless chrysalis or



Egg-pods of a grasshopper, showing various shapes; one opened, exposing the eggs within. Much enlarged. (From Snodgrass. Courtesy U. S. Dept. Agriculture.)

pupal condition, burrow beneath the surface of the soil and there transform without cocoons. Hundreds of species do this, and sometimes these brown pupæ are so abundant that they are turned up in numbers with every spadeful of earth.



A mole-cricket. (U. S. Dept. Agriculture.)

A mole-cricket attacked by the larva of a parasitic wasp. (U. S. Dept. Agriculture.)

It seems perfectly clear that insects must play a decidedly important part in the changes in the character of soil that are constantly going on.

Channel below ground made by the corn-ear worm as it burrows down to pupate. Pupa at end of burrow. (After W. J. Phillips, U. S. Dept. Agriculture.)

Occurring in such countless millions as they do, constantly penetrating the soil in all directions and frequently dragging vegetation below the surface and bringing the subsoil up to the surface, changing the character of the soil humus by passing it through their bodies, and fertilizing the earth by their own death and decay, it is probable that insects are responsible for quite as much soil change as are the earthworms about which Darwin once wrote such an important book.

I have noticed in a recent French journal [1] a worth-while article by F. Willaume in which he makes the following statement (translated):

> The underground fauna is numerous and varied; it includes, besides the species that attack the roots of plants, numerous other species in inactive stages that during their above-ground life attack branches, leaves and fruits of cultivated plants; in this way about 95 per cent of the insects pass a part of their life in the soil.

This seems an astonishing statement, and while I am inclined to believe that the percentage is too large, the opinion of M. Willaume must be taken seriously, since he is a trained entomologist and an assistant to the great French authority Paul Marchal.

We have said something about insects that live underground, for the principal reason that we wish to show the very remarkable range in the methods of life adopted by insects and the extraordinary ways in which they become adapted structurally to such modes of life. For the same broad reason we must consider the insects that live in water.

While there are numerous insects that live all

[1] "Revue de Zoologie Agricole et Appliquée," No. 6 (June, 1930), p. 97. Bordeaux.

their lives underground, there are none that can be called absolutely aquatic. Many pass their early stages under water, but the adults of all live in the free air, and a number of them preferably on land. Of the larvæ that live in the water, the majority breathe by means of tracheal gills: that is, the air-vessels enter branched or filamentary structures issuing from some part of the body, and the oxygen of the water enters them by osmosis through the extremely delicate membrane that covers them. But other aquatic larvæ have no air-gills or only fugitive ones and breathe the direct air (mosquito larvæ, for example) by thrusting a spiracular tube through the surface film of the water.

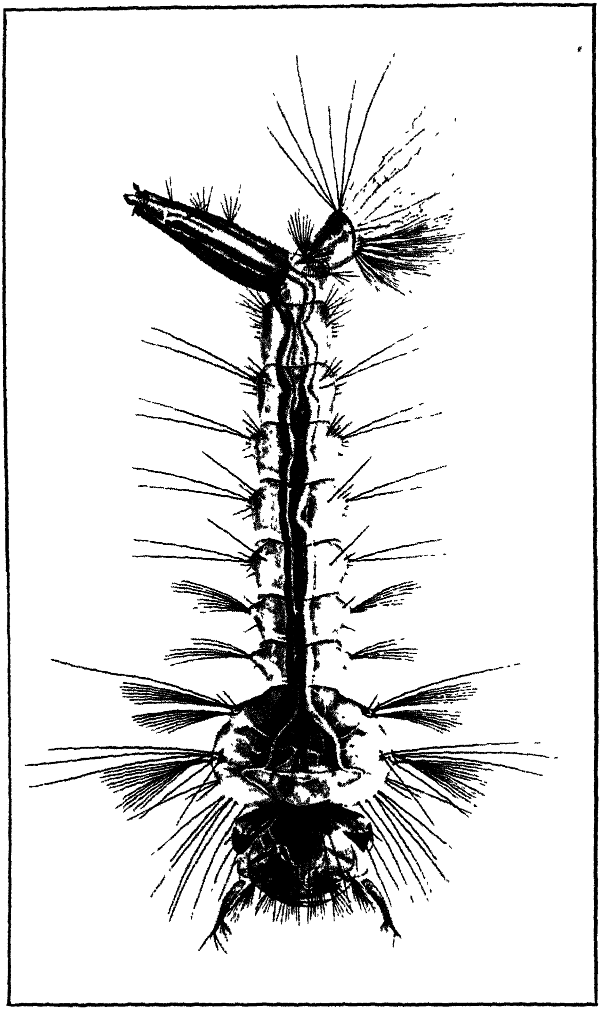
Although many of the underground insects are very injurious to man's interests, possibly the great majority of the aquatic insects may be said to be indirectly beneficial, since they are the food of a number of food-fishes. Certain of them to us are inimical as adults—the mosquitoes again, both as bloodsuckers and as carriers of malaria and yellow fever. The black-flies, or so-called buffalo-gnats, also are in this category.

A great deal has been written about aquatic insects, by many entomologists and in many languages. The best general account (not too detailed) in English will be found in Professor J. G. Needham's book entitled "Life of Inland

Waters." The late Professor S. A. Forbes and his associates in Illinois were among the first to investigate not only the insects of the lakes and streams of that State but the whole fauna of those waters.

Whether the first insects were aquatic or terrestrial is a question, but surely insects have lived in water for countless ages, as is shown by the extraordinary aquatic forms that have been evolved. It appears that nine orders are found commonly in water: the stone-flies, the May-flies or shad-flies as they are called in the northern United States, the dragon-flies, water-bugs, the caddis-flies, many of the net-winged insects of the order Neuroptera, a large number of true flies (order Diptera), several families of beetles. And even a few moths are known whose larvæ are truly aquatic.

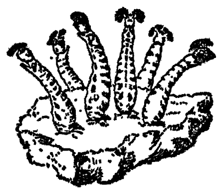
Perhaps even more wonderful is the fact that there are certain minute Hymenopterous parasites that lay their eggs in the eggs of dragon-flies, deposited upon water-plants and often beneath the surface. The little winged parasites, almost microscopic in size, have become able to swim under water, using their wings as oars, and carrying down with them air bubbles to supply the necessary oxygen. And then there is another, larger parasite, as big as some of the Ichneumon flies, that enters the water and lays its eggs in



Full-grown larva of the common rain-water-barrel mosquito—*Culex quinquefasciatus.* (From Howard, Dyar and Knab. Original wash drawing from nature by Frederick Knab.)

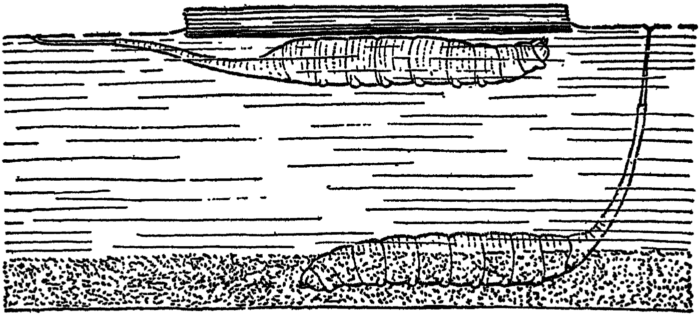
caddis-worms, its larvæ developing and pupating in the caddis-cases. This strange parasite has long been renowned in Europe and recently another species of the same genus (*Agriotypus*) has been found and studied in Japan by Ota and by Clausen.

One of the most remarkable facts is that one or more species of grasshoppers have accommodated themselves to an aquatic life. There are, for example, some small grasshoppers of the genus Scelimena that are amphibious, entering the water and swimming about in it. They are said to prefer, as food, plants growing under water. With these little grasshoppers the hind legs are greatly dilated and are used in swimming. They occur in India.



Larvæ of a black-fly of the genus Simulium. (After Miall.)

Then too there is one of the walking-stick family, not distantly related to the grasshoppers, that in Brazil seeks shelter under stones submerged in mountain streams. It is a wonderfully constructed creature. The under side of its body is hollowed out and various parts are set with dense fringes of hairs. This insect is believed to expel air from the body, causing a vacuum and thus being able to adhere to the upper surface of a stone. There it sits with its head directed



Rat-tailed maggots, larvæ of the drone-fly, which live submerged in water or mud and breathe at the surface through a long tail-like respiratory tube. (From Snodgrass. Courtesy U. S. Dept. Agriculture.)

against the current and its forelegs extended. And we must not forget to mention the Cotylosoma, supposed to be allied to the insect just mentioned. It comes from the Island of Taviuni, and only one specimen is known. It is said to have tracheal gills and spiracles as well.

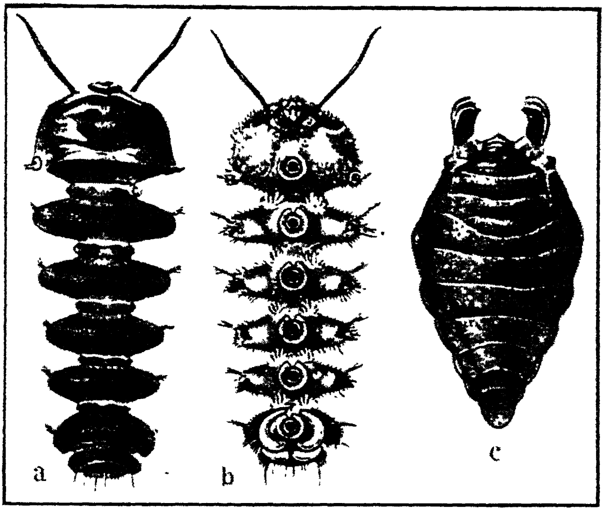
It seems to me that among the aquatic insects we find some of the most highly specialized animals that have ever existed. It would be almost impossible to imagine a more efficient creature than a dragon-fly, for example. Its extremely light yet wonderfully strong body, its marvelous powers of flight, its very large head, turning readily in all directions on a pivot-like neck, its enormous eyes so arranged as to look in all directions, its curiously constructed mouth, the parts of which open very widely, its bunched and forward-directed legs furnished with many grasping hairs—all make it the most perfect animated fly-trap that could be invented, capturing thousands of little insects on the wing with apparently the utmost ease and devouring them with incredible rapidity.

Those who have watched dragon-flies drifting about a small pond or swamp, where they catch and devour their food so quickly that one cannot follow the motions of the legs and mouth parts, have noticed that some of these insects seem to have preëmpted especial territory. Westwood once said that he had seen what he took to be the same individual dragon-fly hawking daily for several weeks over a certain small pond; and Dr. David Sharp knew one that frequented a particular bush, frequently returning to the same leaf to rest after a hunting trip.

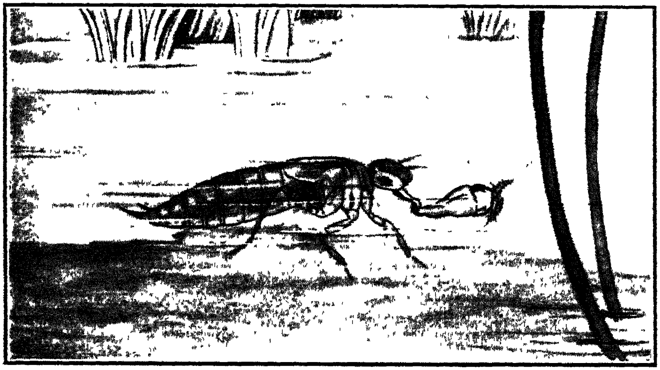
More than forty years ago a well-known metallurgist and railroad builder, Dr. R. H. Lamborn, was so impressed by the efficiency of dragon-flies as destroyers of mosquitoes in the swampy forests about the head of Lake Superior that he conceived the idea that an attempt should be made to multiply them artificially. So he offered three prizes for essays on this subject. The prizes were won by Mrs. Carrie B. Aaron of Philadelphia, Mr. William Beutenmuller of New York, and Mr. A. C. Weeks of Brooklyn, but nothing ever came of the idea; no one ever planned a practical dragon-fly farm. Think of the job of feeding an insect that will eat one after the other thirty house-flies "without lessening its voracity"; consuming its own bulk, in other words, in thirty minutes, being ready for more!

Dragon-fly larvæ are as extraordinary, almost as highly specialized, and almost as efficient as the adults. Nowhere in the whole order Insecta is there a more remarkable development than the labium, or lower lip, of the dragon-fly larva. It has become several times the length of the head. It is hinged so that it can be folded over the face like a mask while the larva is approaching its prey, and it is then suddenly thrust forward to grasp whatever it wants for food. Except in this action of grasping their prey, the dragon-fly larvæ are not particularly rapid movers. They stay at the bottom of ponds and streams, and are protectively colored so that they are not at all conspicuous. They are examples of what Poulton calls "special aggressive resemblance"—that is, mimicking their immediate surroundings for purposes of aggression.

And there is another remarkable and virtually unique structural peculiarity of these larvæ. The tracheal gills are all in the anal cavity and the larvæ are able to pump water into this cavity to gain oxygen and then to force it out so violently



Larva and pupa of the strange aquatic fly, Blepharocera. (After Martini.)



Larva of a dragon-fly, showing the strangely modified protrusible lower lip armed with jaws. (Redrawn from Kunckel d'Herculais.)

that its velocity shoves them forward and the act of expulsion of the water deprived of its oxygen becomes an efficient mode of locomotion.

The dragon-fly is only one of hundreds of differing types of aquatic insects of such diversity of form and method of life as utterly to amaze and bewilder the observer who thinks and wonders how it all came about. Take the caddis-flies, for example. The adults look like rather inconspicuous little moths. These small creatures are often seen around the margins of streams and they frequent shady places. They do not often fly during the day, but are sometimes attracted to light at night. The eggs are laid in a gelatinous mass usually attached to the surface of some water-plant. The larvæ are all aquatic with the exception of one form which lives in damp moss on land. And they are all protected by cases that they make themselves. The cases are composed of leaves either attached at the edges or placed longitudinally, or they may be made of bits of stick arranged in many different ways, or stones or grains of sand; or even water-snail shells may be used for the purpose, attached to the outside of the case, sand being the main material. The larvæ spin silk and fasten all these different substances together, and the cases, which are of various shapes, protect them from fish and from predatory insects.

The study of the caddis-worm is intensely interesting. The head and thorax of the larva are tough, but the abdomen is thin-skinned, delicate, and of a pale color. There are tracheal gills that issue from the sides of the abdomen. When the larva is ready to become a pupa, both ends of the case or tube are protected by silk netting spun by the larva, which then transforms in security. The pupa works its way out, swims to the surface of the water, crawls up on a twig, and casts its skin; and the adult flies away after the wings have expanded.

Most caddis-worms are vegetarians, but there is one group that is carnivorous. As the larva grows it makes additions to the front of its case and casts off fragments from the rear, the diameter of course increasing to accommodate the increasing size of the insect. Curiously enough, there is one group of caddis-flies that make cases of grains of sand and shape them like snail-shells. It is said that a case thus made was once described by a naturalist as a new species of snail.

A very interesting group of semi-aquatic insects—that is to say, aquatic as larvæ and terrestrial as adults—are the midges of the family Chironomidæ. The eggs of some of these midges are laid in gelatinous strings in clumps and usually at the surface of the water. Needham computed one egg-mass that measured bushels in quantity and was doubtless laid by thousands of midges. He says: "Such great egg-masses are not uncommon and they foreshadow the coming of larvæ in the water in almost unbelievable abundance. Midge larvæ are among the greatest producers of animal food. They are preyed upon extensively and by all sorts of aquatic carnivors."

Some of these Chironomid larvæ are the so-called "blood-worms" of the typical genus Chironomus. These apparently helpless and delicate creatures, living in the mud at the bottom of slow streams, and feeding principally upon vegetable refuse, either hide themselves in the mud or make delicate cases of bits of dead leaves, particles of sand, and dabs of mud. And the cases are sometimes so coherent that they can be picked up. Usually they are attached to some fixed object. Professor L. C. Miall and A. R. Hammond of England once wrote a whole book on the structure and life-history of one of these creatures. They found that the larva if undisturbed seldom or never leaves its retreat by day, but ventures out at night and swims near the surface of the water; "writhing in figures-of-eight the body is violently doubled up and then suddenly bent to the other side and the blows thus given to the water propel the larva slowly along." The English writers point out that a store of oxygen is obtained during these nightly excursions and that the supply suffices amply for the following day when the helpless larva does not dare to leave its shelter.

Much might be written about the habits of the stone-flies and of the May-flies or shad-flies, the adults of which become decided nuisances on occasion along the shores of the Great Lakes, simply from their numbers. The Department of Agriculture is often appealed to for some way to remedy this plague of white insects that almost smother people in their open cars at times, but the reply is always given that the larvæ of the creatures are probably the principal nourishment of the food-fish of the Great Lakes and that it would be unwise to attempt to destroy them. The adults of course are perfectly harmless. In fact they cannot feed, and they are troublesome simply because of their incredible numbers.

The insects of aquatic origin of which we most complain, however, are the mosquitoes, the black-flies, the punkies, and the gadflies, or horse-flies. Since the discovery that mosquitoes carry malaria was made by Sir Ronald Ross, in 1898, mosquitoes have been diligently studied all over the world, and the man who does not know a great deal about them must be a very poorly read, not to say unintelligent, person. But with the black-flies and the punkies the case is different. While mosquitoes breed in still water, and cannot successfully emerge in the center of a pond that is big enough so that its surface is riffled by the wind, black-flies, on the contrary, breed only in rapidly running water such as shallow, swift streams with rocky bottoms in the hills and mountains. They may, it is true, breed in sluggish streams, but only where an accidental log-jam or some obstruction has caused the water to "riffle" over some partly submerged object. Only at the point where the riffle occurs are the larvæ of the black-fly ever to be found.

The structure of these larvæ is peculiar. They do not look like insects. Neither do they look like anything else. On the rock-bottom streams near Ithaca, where I spent my boyhood, they used to occur in dense patches on the rocks near the surface of the shallow water. We boys had no idea that they were insects, and called them "leeches," although they have no relation whatever to the leeches. They resemble velvety dark patches upon the rocks. Each larva holds itself erect, attached to a stone or some other object by its hinder end. On the head are beautiful fringes which are constantly agitated in order to bring food within reach.

The pupæ are each placed in a sort of pouch or watch-pocket from which projects the upper part of the body, and this is provided with a pair of filamentous respiratory processes.[2] From their method of life, it becomes obvious that it will be difficult to remedy conditions existing in black-fly country. With still water in which mosquitoes breed, the application of kerosene is a simple matter, but what can one do with a larva that remains fixed in the middle of a rapidly running stream? Summer residents in the Maine woods and in the Adirondacks suffer severely from the attacks of the adults of these insects during the months of May and June, and the New York State legislature during its session of 1929-30, I believe, passed a bill appropriating some money for an investigation of the best means of controlling black-flies and those insects mentioned in the following paragraph, but for some reason it did not become available, and the present State Entomologist, Dr. R. D. Glasgow, is wondering what he shall do if the bill passes again next winter.

The fact that these larvæ apparently can live only in such riffles or shallow, rapidly running streams, shows that they require great amounts

[2] It would seem that the locations used by these larvæ—namely the bottoms of very swiftly running streams or riffles in slow streams—are connected solely with the respiratory function, on account of the oxygenization of the running water—an idea of course intensified by the extraordinary breathing apparatus, especially of the pupæ. It is quite likely, however, that this particular mode of life may very largely have come about through the fact that larvæ living thus are virtually protected from fish. Small fish do not swim in such waters.

of oxygen. And they have been profoundly modified structurally to permit them to hold their precarious position and to thrive under such extraordinary conditions. They have been studied with care for many years by Professor J. H. Comstock and his students at Cornell University, who have pointed out some remarkable facts. For example, Professor Comstock has told me that he has seen the female lay her eggs in the crest of the Triphammer Falls in the so-called "Ithaca Gorge," darting with astonishing rapidity into the running water and emerging almost instantly. Again, he has told me of the issuing of the adult flies—of how they pop out of the swift current like mustard seed shot from a gun. How either of these acts is possible for the little flies is inconceivable, and yet they perform them.

The other group included in the New York State bill mentioned above was one known in the New York woods as "punkies" and in Maine as "no-see-ums."[3] They are diminutive flies of the subfamily Ceratopogoninæ, and other members of this family exist farther south along the seashore and are known as "sand-flies."

[3] "No-see-um" is supposed to have been the name used for these insects by the New England Indians after they had begun to speak a little English. Curiously enough, one of the New England species is named *C. nocivum,* which of course is perfectly good Latin and has a distinct and appropriate meaning.

Unfortunately we are rather ignorant concerning the biology of the punkies. In fact, so far as we know, their lives are varied and offer no substantial suggestions as to how they may be controlled. They are found in Europe also and have been studied to some extent by the Danish writer Wesenberg-Lund. He states that the larvæ live partly in sap below the bark of tree trunks and also partly in water. Those that live under the bark and those that live in water are rather distinct. The former have two pairs of hooked legs at each end of the body and numerous thorns on the body segments. The ones that live in the water lack appendages and have a completely smooth skin. The body is exceedingly thin and long, and if it were not clearly jointed it would look like a roundworm. It swims very well, wriggling the body like a snake. The egg-masses are laid on water-plants at the surface of the water, each mass containing from a hundred to a hundred and fifty eggs. They are common in Denmark in stagnant swamps.

In this country, punkies with both of these modes of life occur, but so far there has been no suggestion for their control. Indeed, control seems almost impossible. Some years ago Mr. F. C. Pratt collected the records of the breeding, and he found that they occurred in the sap of bruised tree trunks, in the water collected in hollow stumps, in human excrement and in horse and cow manure, and also have been found on the under surface of a piece of moist, rotting elm wood and in ants' nests. With creatures of such diversified habits, how is an eradication campaign to be conducted in a summer-resort region in the Catskills or the Adirondacks or the Maine woods? I don't envy Dr. Glasgow if the New York legislature makes its appropriation. But no case of this kind is hopeless.

As to the so-called sand-flies, they belong to the same family as the punkies and have somewhat similar habits. They are found, however, as a rule near the seashore, and much more abundantly in the subtropical regions than in the North. They are frequently pests along the Georgia and Florida coasts as well as in the West India Islands and the Gulf of Mexico coast countries of Central America. Under the auspices of the Medical Department of the United Fruit Company they have been studied rather carefully in Spanish Honduras by several competent entomologists. One of the most interesting reports was made by Dr. R. H. Painter.[4] He discovered five species of two genera, and the larvæ were found either in soil along the edges of pools or in the bottom of shallow accumula-

[4] Fifteenth Annual Report, United Fruit Co. Med. Dept., 1926, pp. 245–265.

tions of water or in the wet area of nearly pure sand just above high-tide level, or in low, wet depressions along the sandy beach. Here again, control measures will be difficult, and as with the punkies, for the present at least, people have to rely upon skin ointments of one kind or another or smudges. Of course local relief can be secured through extensive and costly operations involving much time, labor, and expense in destroying the possible breeding-places around a given point where people must live.

What are known as horse-flies, or gadflies, haunt openings in the woods and are found abundantly along the salt-marshes of the seashore where the woods come down pretty well toward the marshes. Their larvæ are burrowers in the mud at the bottom of ponds and streams. They are carnivorous and feed on the body fluids of snails, aquatic worms, and other animals. The eggs, which are very small and black, are laid in close patches on the vertical stems of aquatic plants. The adults are ferocious biters and are undoubtedly carriers of certain diseases. They may convey the germs of anthrax, for example, and they are responsible largely for the spread of the virulent disease of domestic animals in the Oriental regions which is known as "surra." In Algeria they carry a Trypanosome disease of dromedaries. The larvæ are cylindrical in form, tapering at both ends. They seem to have no heads and no appendages, and the body is translucent and often ringed with tubercles on each segment.

It is being found that the horse-fly larvæ are not so uniformly aquatic as was supposed at an earlier time. A recently published paper by H. H. Schwardt [5] sums up many facts concerning the larval habitat. The author studied 435 larvæ, of which 428 were taken within eighteen inches of the water's edge of ponds or small water-courses, 3 came from a marshy area near a small stream, and 4 were found in decaying oak logs. Certain species live away from water, and larvæ of others are occasionally secured from under logs, stones, and various objects on overflow land that remains moist during the year. Only two species were found in Arkansas under water. One species (*Tabanus vivax*) was found in numbers under stones submerged in from two to six inches of water in small streams, and another species was taken from rice roots in a flooded field. Another species came from decaying oak logs. Loose soils, or those containing a large amount of gravel, are especially inhabited by these larvæ.

Nearly all the aquatic larvæ are confined to

[5] "Journal Kansas Entomological Society," Vol. IV, No. 1, Jan. 1931.

fresh water (only a very few are found in sea-water) and the degree of freshness or foulness of the water varies almost infinitely. We would call some of the material in which they breed exceedingly foul. The drone-fly (Eristalis) has larvæ that live in semi-liquid masses of putridity and gain air through long telescopic anal processes which are protruded to the surface air. A small number of them breed in strongly alkaline water, and almost none are found in sea-water. An exception to this last statement are the larvæ of Chironomus, to which we have referred as "blood-worms." These larvæ can exist at great depths in fresh water (they have been fished up from the bottom of Lake Geneva and of Lake Superior) and also have often been discovered in salt water. Dr. Packard found them abundant at low-water mark in Salem Harbor; Professor Verrill dredged one from a depth of twenty fathoms at Seaport, Maine; and they have been discovered in Denmark, England, and the Isle of Man, breeding in sea-water. It is a well-known fact that the waters of many of the alkaline lakes in the Western States are much more alkaline than sea-water; and in Great Salt Lake, for example, where very few living organisms exist, certain flies of the genus Ephydra breed in enormous abundance, and also in alkaline lakes in Mexico. They are so abundant that they have at times formed an important article of food for the Indians. These same Ephydras have been found in the water of salt-mines, and in the public urinals in Paris.

Schwarz and Hubbard have written most interesting accounts of the insects discovered in the alkaline lakes of the West and also, curiously enough, in the hot springs.[6]

We have noted parenthetically above that very few insects live in the sea, but certain of the true water-bugs of the genus Halobates have been found living on the ocean many hundreds of miles from land. It is in this family of water-bugs (Hydrometridæ) that some of the most extraordinary structural adaptations known in the whole group of insects are to be found. Of the few insects that live during their larval stage in salt water, by far the most conspicuous and notorious are the salt-marsh mosquitoes of the genus Aëdes. While their larvæ do not live in the ocean proper, wherever in all the temperate and tropical portions of the world salt-marshes occur along the seashore, there are pools left by the high tide which are very alkaline and becomes more so as the water evaporates, and in these pools the mosquito larvæ often swarm in countless millions.

[6] "Canadian Entomologist," Vol. XXII (1891), pp. 235–241, 226–230.

It is largely one of these creatures (*Aëdes sollicitans*) that gave New Jersey its former reputation as a mosquito haunt. The State, however, has shown admirable wisdom and enterprise, and for nearly twenty years has been making appropriations for mosquito-control work in cooperation with her townships, including extensive ditching and draining and diking measures that have decidedly curbed the pest along the sea-front. The enormous amounts of money spent in New Jersey as well as in other States should be remembered by the reader when he reaches the section of this book that refers to money loss through insects.

These salt-marsh mosquitoes will breed successfully in marsh pools of which the salt content is considerably greater than that of sea-water. It is fortunate that none of the great malaria-carriers of the genus Anopheles have taken to salt-water breeding, although one species (*A. crucians*) has been found living in salt pools. This particular species, however, is not one of the noted malaria-carriers.

There is so much of interest that might be told about aquatic insects that it is difficult to stop. Writers on this subject have not been numerous, but they have discovered an astonishing number of interesting facts. Among the beetles there are several families that are almost exclusively aquatic. Not only do the large water-beetles of the family Dytiscidæ live under the water in their larval stage but the adults are curiously modified for aquatic life. Their hind legs, for example, have developed into very effective oars; and although they breathe directly at the surface, they can remain under water for a long time without renewing the supply of air. They fly readily, presumably for great distances, and apparently at night. They are obviously in search of new ponds in which to place their offspring, and there are records of rather common mistakes on their part. They have been known to descend on the roof of a greenhouse, having mistaken the glass top for a pond.

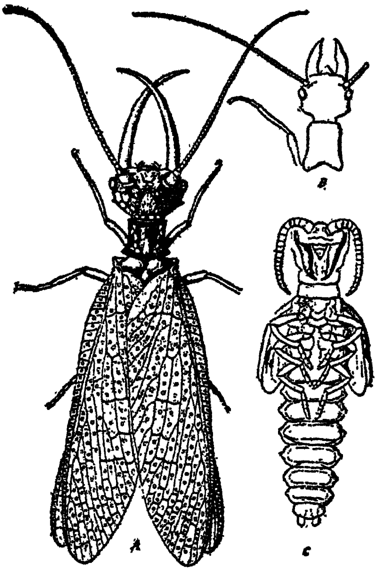
Another of these families of beetles (the Hydrophilidæ) has a curious structural modification which enables it to carry a supply of air down with it. With one species the spiracles are placed near bands of delicate pubescence forming tracts extending the whole length of the body, and with another species cover most of the under surface. These tracts retain a coating of air even when the insect is under the water and moving rapidly, and they are supplied with fresh air by the antennæ of the beetle. The terminal joints of the antennæ form a pubescent scoop made by some longer hairs into a funnel large enough to carry a bubble of air. The insect rises to the surface, sticks out its antennæ, and the air enters and surrounds a large part of the body.

Then there are the curious little "whirligig" beetles, as well as others that live in water. The true bugs (order Heteroptera) have a number of aquatic families. The water-striders and the water-boatmen, as well as the so-called "gigantic" water-bugs, belong here. Many strange anatomical structures have been developed in these insects, and many strange habits. There is one group, for example, where the female lays her eggs on the back of the male, which is then condemned for the rest of his life to serve as an animated baby-carriage.

And there are other great families of aquatic insects, but further comment on this subject must be omitted, except that a word might well be said about the Dobson fly, the apparently ferocious larvæ of which, known as hellgrammites, form a bait well known to bass-fisherman. The eggs are laid in white masses on stones and leaves at the borders of streams, and the larvæ live on the bottom, crawling about or hiding under stones. They are carnivorous, very active, and immensely strong. They breathe by means of tracheal gills along the sides of the body. Their skin is tough, although not horny, which fact of course makes the larva good for bait, since it will last a long time in this capacity.

In the little State of Rhode Island this insect is known by sixteen distinct popular names, which is abundant evidence that it is well known and is decidedly noticeable.

We have seen that the larvæ live under water and breathe by means of tracheal gills along the sides of the body. However, they also have spiracles (breathing-holes) which become functional when the larvæ are full grown. Then they crawl out of the water and transform to pupæ under the surface of the ground. The adult, winged hellgrammite flies are of course air-breathers in the ordinary way.



The hellgrammite fly—*Corydalis cornuta: A,* adult male; *B,* head of female; *C,* pupa. Natural size. (After Riley.)

Before leaving the subject of aquatic insects, it may be as well to refer to the fact that there are numerous insects that evidently can remain under the water for a long time and that probably get their oxygen through the delicate skin by means of osmosis. An Italian writer, A. Ricchello, has recently stated that the very young larvæ of a midge that lives ordinarily in its early stages in the stems of oats will withstand submergence in water as long as ten or twelve days; and we know in this country that the larva of a little snout-beetle called by rice-growers the water-weevil lives on the roots of rice that has been flooded for days and days.

This reminds me that there must be many insects that get their oxygen directly from plant juices. There are the larvæ of one species of mosquito that live indefinitely under water with their breathing apparatus inserted in the stems of certain aquatic plants; and surely the great army of insects that in their larval condition live in the stems of plants or between the upper and under surfaces of the leaves must gain at least a part of their oxygen from plant structures. Obviously the oxygen requirements of many if not most insect larvæ are small.

It has been pointed out by Alfred Russell Wallace and others that the insects living on small islands are in the enormous majority of cases wingless. Winged forms, and especially strong fliers, are carried out to sea and perish. The forms that stay close to the ground and can hold on are the ones that survive and multiply. So the insects that are indigenous to small islands in the ocean have become especially adapted to life there and are able to cling closely to the earth or to the vegetation; and the higher the wind the closer they cling. There have been very many structural adaptations to this particular kind of life. It is true that these adaptations are no more remarkable than those that we see in insects leading other lives under entirely different conditions, but it will be well to mention them here.

An interesting article in the Annual Report of the Smithsonian for 1925, by Major R. W. G. Hingston, on "Animal Life at High Altitudes," brings out a similar condition of affairs. His observations were made on the Tibetan Plateau, a mountainous desert of fourteen-thousand-feet elevation.

In this article Major Hingston refers to insects. He finds that the butterflies are feeble of flight and are unwilling to fly except when the air is still, and when disturbed make but short flights. When they alight they choose sheltered nooks, and when resting spread their wings, pressing them down against the ground. The wings themselves are stiff and rigid, and not likely to be torn on being battered about. There are some wasps and flies and grasshoppers.

His most striking observations on insects were with beetles of the genus Pseudabris which usually hang in clusters on the vetches, where they feed on the young shoots and flowers. When a strong wind springs up suddenly, they drop to the ground, lying apparently dead, each on its side, with its head bent at right angles to the body. Its antennæ are turned downward; its legs are collected into a cluster and thrust out "like lifeless tags. They all lie in the attitude of death, like a crowd of corpses strewn over the ground. When the wind lessens they quickly revive, they run over the soil, regain the vegetation, and climb back to their places on the vetch."

Chapter V

THE PROBLEM CONFRONTING US

CERTAIN geologists and others have proposed for the present age of the world the name "Cenozoic," meaning really the recent age, but interpreted as meaning the age of man. It refers roughly to that portion of the world's history during which the human species has become numerous and prominent and has come to control most of the other species.

But we cannot forget that the rise to prominence of the human species has not been accompanied by any retrogression on the part of the insect type. Indeed, while the advance of the human species has no doubt caused the extinction of various forms of insect life (indirectly rather than directly), insects unquestionably abound now as never before, and the human species, in upsetting what was the former balance of nature, has created conditions peculiarly favorable to many kinds of insects. For example, the Colorado potato-beetle would be rare to-day if man had not extended the range of the cultivated potato westward in the United States until it reached the normal home of this species feeding on its unimportant, wild, native food-plant.

Indeed, I am inclined to follow certain recent authors in terming this colloquially "the age of insects" rather than "the age of man." There is much justification for the name, which I think was first proposed by Z. P. Metcalf.

Not only is there no doubt that insects abound now more than ever before, but it is undeniable that the human species, since it began to cultivate crops and to build cities and to become civilized and highly inventive and efficient, has been responsible for at least part of this increase. Humanity has created conditions peculiarly favorable to certain kinds of insects and they are multiplying as they never would have done had not man given them a chance, and, by providing them with enormous quantities of food and placing it before them in the most inviting way, fairly begged them to do their worst and to exercise to the utmost those extraordinary powers of multiplication of which we have written in previous paragraphs.

Some of the greatest menaces to agriculture in the United States have met with this overhospitable treatment on the part of the American farmer. Take, for example, the cotton boll-weevil and the European corn-borer. The former would not have spread over the whole cotton-belt and caused hundreds of millions of dollars' worth of damage had it not found, on crosssing the Rio Grande, that cotton was planted and cultivated and harvested in precisely the way to encourage the mutiplication of the weevil and to hasten its spread to an extreme. The corn-borer would not to-day be the menace it is to our greatest agricultural crop if we did not grow the crop just as we do, in enormous fields, leaving the stalks to stand through the winter.

The studies of the entomologists in these two cases have been so thorough as to have demonstrated conclusively that a variation in the farm practice in both cases would have been effective and would have prevented great loss. The entomologists warned the cotton-planters more than twenty-five years ago that they should plant the seed of early-maturing varieties of cotton, should force the crop, and destroy the stalks by the end of October. They told the corn-growers that they should not leave the corn-stalks standing in the field during the winter and all the early spring, but should cut them close to the ground or pull them up and, where other use was impossible, should bury them or burn them.

The farmers, however (at least many of them), seem unwilling to be told how to do things. As a class, they have shown themselves in the past to be reactionary, and from this tendency they are advancing too slowly. While they complain bitterly of untoward conditions, they do not like, apparently, to change their methods even in the face of predicted ills.

We have seen two striking instances, but there are many others. While we cannot say that as a rule crops are grown in just such a way as to encourage the multiplication of injurious insects, it is surely true that many crops are grown in that way.

Before we leave the subject of the European corn-borer, I am impelled to tell a story which is apt just here: In 1926 the German Ministry of Agriculture started a laboratory at Rastatt in Baden for the study of the European corn-borer. This seemed strange to me, as corn is not cultivated to any extent in Germany, and I wondered at what seemed to be a useless expense. In August, 1927, however, I met in Munich Dr. W. Zwölfer, the expert in charge of the Rastatt laboratory, and in answer to my questions he explained that the German Government intended to encourage the cultivation of corn in the south of Germany and that it did not wish to begin without understanding how to combat this destructive native species, believing that if the proper cropping practices were adopted the damage could be avoided.

It is perfectly obvious to all thinking entomologists that the general statement just made, while, applying to a number of the principal crops and their insect enemies, applies equally well to a host of unnoticed insects which, while they bring about no strikingly noticeable loss, nevertheless must reduce crop values to a very considerable extent when considered as a whole.

From time to time I have met administrative officials in the Ministries of Agriculture of different European countries, who have asked me about insect damage in the United States and have said: "The necessity for such a service as yours [referring to the Bureau of Entomology of the United States Department of Agriculture] in your great new country is obvious, but here in Europe, where we have smaller holdings and where we cultivate closely, we have no great insect ravages." In reply I called attention to the fact that all through the summer millions of tiny mouths, millions of tiny beaks, are taking nutriment from cultivated crops in every country in Europe. If it were possible to estimate the money loss through this unnoticed drain the result would be astounding. Surely crops of much greater size could be raised on the same land if this insect drain could be eliminated, and surely the drain will increase if exactly the present methods of farming are continued.

Here and there, with many crops, the entomologists have pointed out just how the farmers had been helping the insects, and occasionally the entomologists' advice has been heeded, always provided that it involved only simple and economical changes. A noticeable instance of this was the disappearance of the clover-seed midge as a pest in the Eastern States, in the early 1880's, by the advancing of the date of cutting the first hay crop ten days. Had this not been done, the insects would have completed their growth, transformed to adults, and deposited innumerable eggs in the forming flower heads of the midsummer crop.

Possibly the foregoing is enough to indicate how present-day agriculture is favoring the rapid increase of insects.

The same general statement may be made with regard to the insects concerned in the carriage of human diseases. For example, it is undoubtedly true that the advance of civilization in a new country at first reduces malaria, by the drainage of swamp areas and the reclaiming of moist "bad lands" for agriculture; but the disease reappears as the country becomes densely settled, since man has made new and even better breeding-places for the malarial mosquitoes than were the old swamps. The making of mill-dams and of stone quarries; the stopping of very small streams of running water by railway embankments; the digging of borrow-pits; the accumulation of old tin cans and disused vessels of one sort or another about towns; even the footprints of domestic cattle in soil that is not too dry, especially during a rainy season; water-troughs for cattle; small ornamental ponds for aquatic plants; poorly protected cesspools; imperfectly covered water-tanks; the fire-risk barrels of water on the great freight platforms in the cotton regions of the South; the catch-basins of sewer systems, and the badly cared for roof-troughs of houses and barns—all make admirable breeding-places for these mosquitoes.

It must not be forgotten also that the yellow-fever mosquito has in the course of time become almost a domesticated animal. Apparently it no longer breeds in the wild. It seems absolutely dependent upon the conditions under which human beings live, and breeds to the extreme in domestic accumulations of water such as those rain-water barrels and all the water-holding vessels about houses and towns; and one hardly realizes their great number until one begins to search for the breeding-places of this particular mosquito. Even the holy-water fonts in churches seem favorite breeding-places. The probabilities are that before it encountered civilization this species inhabited tree holes and that therefore it was not very numerous. The coming of civilization increased its possible breeding-places beyond measure.

I hardly think it necessary to spend any more words on this aspect of the subject, but it will be worth while to consider for a moment how man has facilitated the spread of injurious insects from one region to another. Rather more than thirty years ago I wrote an address entitled "The Spread of Land Species by the Agency of Man with Especial Reference to Insects," in which I summarized the facts as I knew them then, that the carriage of injurious insects from one country to another was, as was quite to be expected when one stops to think about it, due almost entirely to man, and of course very largely to commerce. Countless insects have been accidental passengers on vehicles, railway trains, and sea-going vessels, but the majority of insects carried for long distances have been feeders on or in substances carried in trade or, in the case of vessels, for the subsistence of the crews.

The insects affecting stored foods, for example, are now almost cosmopolitan. It is difficult to decide where most of them originated.

The same may be said for certain of the insects attacking plants. The introduction of useful or ornamental plants from one country to another has been going on for years. Inconspicuous insects, like stem-borers or root-borers or scale-insects or plant-lice in the egg stage, have thus been carried everywhere, and with many of these, as with the stored-food insects, it is difficult now to know their original homes. In fact, in a comparatively new country like the United States, the great majority of the principal insect pests have been brought in as described above.

The Hawaiian Islands originally were singularly free from insect pests, and virtually every injurious insect existing there to-day has been imported. For example, there seem to have been no mosquitoes there until they were brought in, breeding in the water supplies of sailing-vessels. It is said in Honolulu, with a smile, that the mosquitoes and the missionaries came in at the same time. It is undoubtedly true that the historic epidemics of yellow fever in Norfolk, Virginia, and in Philadelphia in the last century were due to the introduction, by ships, of the yellow-fever mosquito.

As to the great insect pests of the United States, the codling-moth of the apple probably came originally from Europe, in the chrysalis stage, in the cracks of barrels and boxes that had held apples; the Hessian fly is said to have come in the straw used as bedding for the Hessian troops during the War of the Revolution; the gipsy-moth, originally brought in in the egg stage in the course of a scientific experiment, has been found in the egg stage many times on plants brought from Europe; the brown-tail moth came over in its winter nests on rose bushes imported from Holland; the Japanese beetle was introduced in the grub stage in earth about the bulbs of iris; the cotton boll-weevil came up from Mexico in cotton taken across the Rio Grande to be ginned; the European corn-borer was in broom corn imported from Hungary; the alfalfa weevil was probably brought over in alfalfa straw used in packing. It is safe to say that without the help of man none of these insects would ever have reached the United States.

Since the address to which I have just referred was delivered (in 1897) the rapidity of intercourse between different countries and between different parts of the same country has increased greatly. Steamships are making quicker passages, the automobile has come into universal use, and now flying-machines bid fair to make international transport still more rapid.

Let us take the automobile, for example. Automobiles carry very many insects. Every driver of an automobile, after a long tour, has found the radiator on the front of his machine almost covered with insects—some dead, of course, but others still living, and these may have been carried for long distances. When an automobile passes through a wooded district in the summertime, the insects fall from the trees upon the car, crawling caterpillars attach themselves to some part of it during halts and are thus transported for miles. A notable example of this is the Peace Conference held at Portsmouth, New Hampshire, after the Russo-Japanese War. Tourists from all parts of New England were attracted to Portsmouth by the conference, and, as this was in the month of June when the caterpillars were crawling, the territory inhabited by the gipsy-moth was very largely extended.

In more recent years several interstate quarantines have been established against the spread of pests already present in certain portions of the United States, and in some of these quarantines the United States Federal Horticultural Board has been especially interested. California is particularly noted as a State which has long protected herself by quarantine measures, against pests from foreign countries and against notorious insects, such as the alfalfa weevil, likely to enter from adjoining States. Many other States have recently adopted similar measures. In addition to these, the authorities of the United States Department of Agriculture have carefully and continuously mapped the regions already occupied by such pests as the gipsy-moth, the Japanese beetle, and the European corn-borer, and has established, on the border-lines of spread, means for the inspection of all products likely to be infested.

In the spread of the insects named, the automobile would be extremely active without such quarantine and inspection. The rapid improvement of roads in recent years, and the consequent enormous increase of long-distance automobile tours, have greatly augmented the difficulties of this branch of the government service. Thousands of tourists pass through many States each summer. Many of them are campers. Many of them buy green corn and other vegetables likely to contain the Japanese beetle and the European corn-borer, and would carry them on from State to State if not stopped by the inspectors.

It seems that insects take advantage of almost every change of habit of the human species, of every so-called advance in civilization, but occasionally such a step by humanity unwittingly results in a very important check to some insect enemy. We have just seen how the automobile greatly facilitates the long-distance spread of many injurious insects, but we must not forget that the extraordinarily rapid supplanting of the horse by the automobile and the consequent disappearance of horse stables in modern communities has enormously lessened the numbers of the disease-bearing house-fly which formerly bred most prolifically in the horse manure that abounded. I rather enjoy the thought that I predicted this outcome as early as 1896, when the "horseless carriage" was in its infancy.

But there is another and more rapid method of locomotion which is coming into use and promises enormous developments in the near future—the airplane. In 1920 I heard Dr. T. Chalmers Mitchell address the Zoölogical Society of London on the subject of an attempted airplane journey from Cairo to the Cape. In the course of that lecture he mentioned the airplane incidentally as a spreader of insects. He also mentioned the extremely interesting fact that during a one-night halt, the wood skids and frame of the airplane were attacked by white ants.

Fortunately, within the last few years some observations on this point have been made by a competent entomologist. In the course of his experimental work in the use of the airplane against the cotton boll-weevil, Mr. B. R. Coad, of the cotton-insect laboratory of the United States Bureau of Entomology at Tallulah, Louisiana, has made numerous airplane flights; and some of his force, notably Mr. P. A. Glick, have done the same. Incidentally these men have made very interesting studies of the insects of the upper air. They have arranged to capture those that happened to be flying at different heights, and have found to their surprise that insects are found at great altitudes. Naturally, in its rapid passage through the air, all insects that happen to alight on the airplane are swept away by the wind; but the inside of the plane is so constructed that, according to Mr. Coad, while on the ground it makes an ideal hiding-place for many insects; and he tells me that he freqently observes these while the plane is in flight.

In a letter that Mr. Coad wrote me on November 10, 1927, he goes into this subject rather fully:

Practically the entire fuselage is available for insects to crawl in and rest or hide, especially the rear end from the last cockpit to the tail is nothing more than a box construction with many cross wires and other braces affording an ideal resting place for insects. Mr. Glick tells me that in using his insect trap, he finds it absolutely necessary to go into this thoroughly each time before he leaves the ground as he usually finds a number of insects which have crawled into the empty side and hidden. Furthermore, Mr. Glick reports that while flying for trap collections, he has observed the following insects in the cockpit with him: mosquitoes, cockroaches, houseflies and leaf hoppers. Personally, I have very frequently watched insects remain in the cockpit with me for a flight lasting several hours. Probably our most frequent passengers are the mud-building wasps. These find the numerous tubes and other small holes in an airplane ideal places to build their homes and they are really quite a nuisance. During their most active season, we have to maintain practically a daily check because of their habit of filling up important lines with their mud homes. On one type of ship particularly, a serious trouble has developed several times due to the fact that the levers operating the flying controls are built in the interior of the wings and the wasps will get into the wing and fill up important connections and moving joints with mud. I remember very vividly one occasion on which a wasp started out with me in the cockpit and managed to get up my trousers leg when we were several thousand feet in the air. On still another occasion, a family of *Solenopsis* moved in with me and some time later decided that they needed to get closer for warmth and comfort. Apparently almost any insect which can fly or crawl into the interior of the plane is subject to such transportation and I imagine that those species which hunt sheltered nooks for hiding are going to be particularly liable to such movement. Certainly, in years to come, a quarantine measure attempting to restrict movement of insects will be forced into consideration of airplane transportation. I have frequently observed an interesting example of how this may take place. I have a habit of eating peppermints practically all the time I am flying to keep me from wanting to smoke and I always carry several packages of these in the pockets of my flying suit. These frequently spill out and lodge in the bottom of the fuselage below the floor boards where they are rather difficult to reach. On several occasions while flying, I have noticed some of these candies lying in the bottom of the fuselage completely covered with sweet-eating insects which have been attracted to this feast while the plane was resting on the ground. Undoubtedly, as the use of planes develops, there will be more and more instances of the plane becoming contaminated with material attractive to insects, and thus the population will be increased above that provided by the incidental passengers or those which seek the planes for the purpose of hiding.

These are merely some of the possibilities which have been indicated by present experience, and of course, as the use of the plane develops, we will get more and more instances of the sort.

Since this letter of Mr. Coad's was written, his upper-air work has developed greatly. He finds enormous numbers of insects carried up by air-currents. He has found them up to eighteen thousand feet. Unexpectedly, he has discovered a large number of delicate forms that have no great powers of flight. Not only this, but he finds absolutely wingless forms that have been carried up by the air-currents to extreme elevations. Diminutive creatures like plant-lice, young leaf-hoppers, and others are common examples. Of course many of these are dead; the cold of the high elevations kills them. Nevertheless, not only is it shown by his work that insects are distributed much more widely through the air than had been suspected, but the danger of airplane carriage of injurious forms becomes strikingly evident.

The truth is that the human species has been creating a tremendous disturbance in the world of nature. In regions where things had pretty well settled down and where the interplay of natural factors was fairly well established, man, swiftly increasing in number, has altered conditions in the most extraordinary way. Nature tries to adjust herself to the new conditions man has created and which he also is fast changing. Nature has a hard job, but she is powerful and resourceful. Man's most important rivals, the insects, take advantage of every opportunity. Man has nearly overlooked these apparently insignificant creatures; but, alert, adaptable, and capable of quick and enormous multiplication, they never lose a chance to enlarge their field. Man in growing more food for himself creates more for them, and unless their possibilities are considered carefully in a thousand ways the final effect will be disastrous.

I have just found a hitherto unnoticed paragraph in George H. Carpenter's admirable book "The Biology of Insects," published in London in 1928. He puts the situation very precisely, and like the conservative Englishmen that he is:

> We have already seen that there is mutual action between insects and mankind in their food-gaining activities; the practice of agriculture and gardening, by crowding together on a comparatively small area of land enormous numbers of plants of the same kind, cannot but lead to rapid increase in the numbers

of those insects of the district which can feed on the cultivated plants. Thus cultivation tends to incite various insects to become pests, and then the cultivator finds it needful to take measures for the slaughter of the pests on a large scale. Similarly the shepherd and the cattle-owner collect in a restricted area flocks and herds of animals of the same kind, whose large numbers and ready accessibility must tend to abnormal multiplication of parasites of all groups. It is right that men, annoyed by insect pests, should remember to how great an extent the troubles that beset them are the direct consequence of their own actions.

At a meeting of the Eastern Branch of the Association of Economic Entomologists, held in New York, November 21 and 22, 1930, Dr. Hugh Glasgow of the Geneva Agricultural Experiment Station read a paper on the rust-fly of the carrot. This is a case in point. It seems that carrots in past years have never been a crop that counted for very much. They were grown in vegetable gardens and they were used for certain purposes, but not extensively. Of late years, however, there has sprung up a great industry—the preparation of canned soups—and this has brought about a wide demand for carrots. As a result, these vegetables have been planted over large areas in central New York and elsewhere. One can guess what happened. A paradise for the carrot rust-fly was created. A whole world of riotous living was opened before it. The destructive insect multiplied beyond measure. Dr. Glasgow expressed it in some such way as this: "Had the farmers been trying to raise rust-flies instead of carrots, they could not, by the utmost ingenuity, have devised a better way."

I thought, as I listened to his paper, of another incident. When we were preparing for war in 1917 there was a great demand for castor-oil, to be used in airplane operation. Bounties were offered by the Government for castor-beans. Large areas were planted in Florida. Now, the castor-bean growing in dooryards as an ornamental plant is either not affected at all by insects or very slightly so. But when these wholesale plantings took place in Florida, more than one species of insect found the bean palatable, and the enormous supply of food brought about a rapid multiplication of insects. The common so-called grass-worm of the South (*Laphygma frugiperda*) seemed especially to relish this new "staff of life," and distress signals were displayed by the planters. The leaf-feeding caterpillars were of course easily controlled by arsenical sprays, but the cost of growing the plants was considerably increased.

Of course we will not let these conditions persist or grow worse if we can avoid it, but with the help of mankind insects will destroy their helpers. It is probably safe to say, however, that without assistance from man insects will remain just one element in the biological complex—as it was before man's advent. We have no reason to think that without the advent of man, insects, fit as they are and persistent as they are as a type of life, would ever have become dominant in the world. They had existed for millions of years, consequently becoming fitter and fitter for earth conditions. But there was a balance. They formed the food of vast numbers of aquatic animals, birds, reptiles, and even certain land mammals. They preyed upon certain types of vegetation, but probably aided, by the destruction of some kinds of plants, in the promotion of the growth of some other forms. On the whole, in the so-called "battle of the forest" they probably helped to make a finer forest. With the coming of man, however, the conditions mentioned in the previous chapters gradually developed. The insects have profited by human necessities, and humanity has virtually ignored the insects even though suffering tremendous loss from their work.

We may be sure that we are not going to continue to encourage this disastrous increase of insects. But supposing we were to continue old methods, that we were to ignore the menace, what would result? Unquestionably mass starvation of humanity and the dominance of the insect type in this world until nature strikes a new balance and evolves competitive types better fitted to maintain themselves than the human species will have shown itself to be.

There is much room for imaginative writing in the way of the possibilities of insect injuries. Melville Davisson Post wrote a strong story three or four years ago which brings in a South Pacific island that was extremely fertile and grew luxuriant rice crops. Insects did not do much damage, since they were held in subjection by the birds. And everything was lovely. An enterprising white man introduced arsenical poisons against the insects. Some birds were killed and the rest deserted the island. The insects multiplied until they ate every living plant. People died, and when the final lone rescuer reached the spot, only a dying missionary, his beautiful daughter, and a designing Chinaman were left. All this sounds ridiculous, but it is a good story, like all of Post's, and while the importance of birds is tremendously over-emphasized, the insect danger is shown up strikingly.

The money loss and the labor loss have often been discussed, and from various angles. There is room for differences of opinion. A facetious friend said to me once that he had heard entomologists and plant-disease men and Biological Survey men talking about percentages of losses through the work of insects and other animals and plant diseases, and had made up his mind that in the average year 120 per cent of all of our crops were destroyed! Of course there is a tendency on the part of enthusiastic workers in every line of human endeavor to exaggerate the importance of their labors. So let us try to be fair. Dr. Marlatt, who from time to time has devoted much thought to this subject, once said at a symposium on insect damage:

"We, as insect-loss statisticians, may get too close a view of our subject and lose the necessary contacts or perspectives. It is important to remember that we are not alone in the field of estimating plant-pest damage. There are the phytopathologists, nematologists, ornithologists, and mammalogists, to say nothing of the ecologists and other ologists, and all of these must have their rake-off. In our estimates we must take account of all these factors and leave a little over for the other fellow, and a little over, after all that, for the farmer. He must have something!" [1]

[1] In fact, jokes about statistics have become rather a fad; and especially fun has been poked at the statisticians in Washington, D. C. For example, I quote the following from a Kansas City newspaper: "As the picnic season is coming on we are going to watch the mails from the capital city. We are anxious to know just how many million dollars' worth of cake and pie the ants are going to devour

For the United States, it has seemed to people closest to the problem that Marlatt's estimate of 1916, which was based on the crop values as recorded by the latest census and a certain definite percentage of loss from insects, was probably correct—that is, something over $1,100,000,000. To this amount there was added an estimate of the other damage done by insects, bringing the total to more than $1,500,000,000 each year.

If we are to use virtually the same percentages of loss that were used in this estimate, and try again on the basis of the census of 1920, we reach the astonishing figure of more than $2,200,000,000. Of course it will be recognized that 1919 was a year of comparatively high prices, which was especially the case with cotton; so that it is not fair to say that the total sum just mentioned represents an average annual loss; indeed, every statistician recognizes that there is an economic fallacy in estimates of this kind, owing to the fact that a decrease in production is followed by an increase in price. It would be better if we could estimate the loss in terms of weight or measure rather than money value, but this would not afford us terms applying to all losses. So that we would seem to be

while we are pitching horseshoes and shooting bullets at a target. But still of greater interest will be to learn how many legs the flies have left in the butter."

compelled to do the best we can with the money values.

Considering the statement that prices are regulated by production, the factor of distribution often comes in in such a way that in a given country large crops may produce good prices and small crops low prices. Marlatt, in his 1916 paper, pointed out that for a long series of years the price of wheat in the United States exhibited little or no relation to our own production. He showed, for example, the striking fact that the bumper crop of 1901 brought to the farmer twenty-three cents a bushel more than the crop of 1894, which was 300,000 bushels less. He also pointed out that, as an offset to increased values due to lessened harvests caused by the work of insects, there are other items to be considered. He not only mentioned the cost of spraying and that sort of thing, which runs into the millions, but showed that there are exceedingly important secondary losses resulting from diminished production. Thus, an excessive reduction in winter wheat will be a serious drawback to milling operations through the affected region; a shortage of cotton, through the attacks of the boll-weevil or other insects, will cause the shutting down of cotton-gins and cotton-mills, and a shortage of grains means a loss to the railroads and other transportation companies and to shippers. He adds, "Any material shrinkage in an important product starts a train of losses to the end of the chapter, the total amount of which is quite beyond calculation or estimate."

On the whole, I am inclined to believe that the sum mentioned is a conservative estimate of our losses through insects. There are so many things to be considered that tremendously complicate the methods of arriving at conclusions within hailing distance of exactitude. We should think of the point that every citizen of our country is affected by the destruction of any large percentage of any farm crop. It may be that, because of increased prices for the portions not destroyed, the farmers of the country as a whole may not lose, but these increased prices affect every consumer, so that there is in that way a loss that cannot be estimated.

And there is an enormous loss, almost entirely unappreciated, by the work of myriads of insects. There is tremendous damage to stored products (and this includes hides and wool), to clothing, to forests and forest products, to live stock, and to man himself through diseases that are insect-borne. And there are insidious and unsuspected losses going on all the time through the work of household insects of many different kinds which affect nearly all of our cherished possessions.

In agriculture a very large part of the work of injurious insects is unnoticed. The loss of cotton through the work of the boll-weevil, or of wheat through the work of the Hessian fly, or of apples through the work of the codling-moth, or of stored grain through the work of grain-weevils, is all obvious and the totals can be estimated; but in many ways insects are working unnoticed even on crops, causing great loss.

A good example of this was cited years ago by Professor Herbert Osborn, who was working with the leaf-hoppers. These little insects abound in grass-lands; they hop about your feet as you walk through pastures; but the pasture may be apparently in good condition until it is put to the test. And this is exactly what Professor Osborn did. He constructed an apparatus on a large scale, which he called a tar-pan, and dragged it through a certain definite area of fenced pasture, thus removing the bulk of the leaf-hoppers. Another field, comparable in size and fertility, also was fenced in. It was found that two cows could be supported in good condition upon the pasturage of the first field, whereas in the second field there was barely enough for one cow. This means that one half of the money value of the pasturage in the second field was lost through the work of leaf-hoppers, although to the casual eye the two fields looked about alike.

This is surely indicative of what is happening all the time. There are millions of tiny mouths continually working on our crops, and what is now considered a normal crop could in many instances be decidedly increased if this unsuspected drain could be stopped. I made this point a few years ago in talking with the Minister of Agriculture of Poland, in reply to his statement that economic entomologists are important in countries like the United States, where great insect outbreaks like those of the boll-weevil and so on occur, but that in Poland there were no such plagues, and therefore the need for the economic entomologist was comparatively slight.

We should remember the immense amount of money that is spent in different ways in fighting insects, the amount spent for insecticides and insecticide machinery, which would be extremely difficult to estimate. And there are many other expenses. Take, for example, the screening of houses to keep out flies and mosquitoes. It is not generally realized that a few years ago, in a single season, thirty millions of dollars' worth of screening was sold by the manufacturers *in the roll.*

I have referred, in an opening paragraph of this section, to the plant-disease people as having their own estimates of loss. Within recent years it has been discovered that innumerable plant diseases are carried by insects, and that the losses from plant diseases may to a very considerable degree be placed against them. While this fact only complicates our attempts to reach a just estimate of annual losses of the sort, it surely affords another argument in support of the work of the economic entomologist.

When we come to consider the question of loss to the human race through insects that carry diseases of man, we may find it possible to make a rough estimate of the loss annually in terms of dollars and cents, but this will not afford anything like a just estimate of what these insects have cost the human race in times past or of what they may cost us at any time in the future. When we think of the plague years in Europe, during which the progress of civilization was absolutely set back in a startling way; when we think of the death of a million persons a year in India from plague and cholera, we cannot express ourselves in concrete terms. Coming nearer home, I wonder if any one now can form a faint idea of the check to industrial development in our Southern States by the constant danger of yellow-fever epidemics during the whole of the last century, or of the serious interruption to commerce and industry by such epidemics when they did occur. Figures cannot show all this.[2]

Reverting to the total mentioned, namely \$2,200,000,000, in that estimate, on the basis of cotton losses of 10 per cent, the sum amounted to \$235,000,000. But let us take the cotton crop of 1921, when normal production was reduced by 5,240,000 bales from the work of the boll-weevil. According to the estimate of the Department of Agriculture, there was a minimum loss that year from the boll-weevil of \$524,000,000.

It has been suggested, after considering all of the difficulties concerned in the formulation of insect losses, that if we could express it in the terms of lost labor we might be able to get a better and more accurate picture of the situation. Some years ago I put this question up to the Bureau of Agricultural Economics of the Department of Agriculture, and they began to give the matter careful consideration. No definite reports, however, have as yet reached me. Nevertheless, if our money estimates are at all within touch of the truth, it is obvious that the work of a million people in this country every year is lost through insect damage, and I feel sure that if the agricultural economists continue their work, taking principal crop by principal crop,

[2] A statement by a credible authority that I saw some ten years ago made an estimate of nine hundred million dollars annually as the loss in the United States through malaria.

we shall find that, taken as a whole, the picture is even darker.

It is important to add that, while he was chairman of the Federal Horticultural Board, Dr. C. L. Marlatt, now the Chief of the United States Bureau of Entomology, thought about the question of damage done only by those insects that have been introduced into this country, and he came to the conclusion that, as he expressed it: "The board bill of introduced farm and fruit pests is now more than a billion dollars a year! In bad years it is much more! Two hours of every day's work on the farm or in the garden and orchard go to feed these uninvited guests."

The latest attempt to estimate the annual insect damage in terms of money is in the volume entitled "Destructive and Useful Insects," by Metcalf and Flint, published at the close of 1928. Their total estimate for the United States is $1,590,044,500. This in my opinion is some hundreds of millions of dollars too low.

At the conference of Empire entomologists held in London in 1930, under the auspices of the Imperial Bureau of Entomology, one of the subjects considered was the money loss in the British Empire through the work of insects. It was stated that in Canada the losses to field and fruit crops and forests had been estimated at

30,000,000 pounds ($150,000,000) per annum. In Queensland these losses were estimated at 2,000,000 pounds ($10,000,000) including damage to the cattle industry. For the Indian Empire the loss to agriculture, including that in domestic animals and animal products, was estimated at 151,000,000 pounds ($755,000,000).

Interesting deductions were drawn from these figures and from the comparative losses in the United States and the comparative expenditures by the United States and the British Empire. It was pointed out that the United States, with a population of about 120,000,000, spends at least $10,000,000 a year and employs not less than 500 entomologists, while the British Empire, with a population of nearly four times the size, spends little more than one fourth of this amount and employs less than 300 entomologists. If the expenditure on entomology in relation to the total revenue were on the same basis in the British Empire as in the United States, the empire would be spending nearly seven times as much as it actually does. The relative responsibility of the United States and the British Empire was also brought out. The empire, being scattered throughout the world, is concerned with a greater range of insects and crops. Problems in the United States, though on a vast scale, are limited in variety, and neglect of them would not be as dangerous to the rest of the world as is the case in the British Empire.

Comparatively few estimates of damage have been made in other countries. In 1926, Dr. Ludwig Reh, of Hamburg, estimated that the grapevine Phylloxera cost Germany $250,000 a year, and that in fifty years the same insect cost France $6,000,000,000. The olive-fly is said in this statement to cause an annual loss in Italy of $3,000,000. A little grape-moth known as *Clysia ambiguella* is said to have caused damage in 1897 in France and Germany to the extent of $27,500,000. It is further stated that May-beetles cause a yearly loss in France of from $50,000,000 to $200,000,000. Dr. Reh points out that in Algeria in 1866 locusts were responsible for a famine with a resultant epidemic that destroyed 5 per cent of the population. He places the annual loss from farm and forest insect pests in Germany at $500,000,000.

Regarding the amounts spent in insect warfare much more might be stated. For example, Professor Herms of California in 1924 estimated that the amount expended in control that year in the State was $11,500,000. Using the same percentage of crop values by States for the whole United States, we would arrive at the sum approximately of $224,000,000 spent in fighting insects affecting crops. I imagine that this may be too high, since the percentages are not uniform in different parts of the country. Many States, however, may spend more. Dr. A. L. Quaintance, with whom I have consulted about this question and who is perhaps in better position to call the whole field into his mind than any other person known to me, is inclined to think that $200,000,000 would be a conservative estimate.

Coming down to very recent times, I notice in the Annual Report of the Agricultural Commissioner of the County of Los Angeles, California, for the year July 1, 1929, to June 30, 1930, that the annual cost for the treatment of Citrus orchards for scale-insects in the one county of Los Angeles during the preceding seven years amounted to $1,377,084, and that the actual losses were estimated at double the cost of treatment. In other words, more than $4,000,000 is paid annually by growers of Citrus trees as a levy to scale-insects and their control.

The amount expended for the purchase of insecticides is very great. I happened the other day to notice the statement that in 1924 3,000,000 pounds of Dalmatian powder were imported, and in 1928 13,000,000 pounds. Arsenate of lime must be used by the millions of pounds in the South, and arsenate of lead or substitutes also by millions of pounds in the orchards in the North.

The United States Bureau of the Census issued a statement, November 3, 1930, under the census of manufactures for 1929, in which information is given about insecticides and fungicides for use in the household and for agriculture. It is unnecessary to reprint the table; it is enough to indicate that the total value of the insecticides and fungicides amounted to $23,-200,164, and of this amount the household insecticides summed up $13,349,461.

In their estimate of the manufacture of miscellaneous chemicals for 1929, the Census Bureau shows 31,314,176 pounds of arsenate of calcium at a valuation of $1,733,600; of arsenate of lead, 29,903,552 pounds at valuation of $3,304,351, and nearly $500,000 in magnesium arsenate, sodium arsenate, etc. Then, among other things, $2,859,-554 worth of carbon bisulphid was used, a certain amount for insecticide purposes, and $1,728,013 worth of carbon tetrachlorid was manufactured, part of which was used for insecticide purposes.

Chapter VI

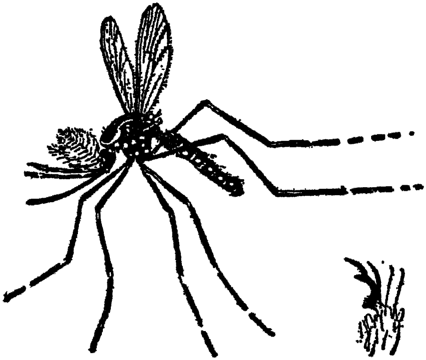
INJURIES ASIDE FROM DAMAGE TO CROPS

In the preceding chapter we have considered the money loss and the labor loss through the direct work of insects in the destruction of growing crops, stored products, and other property. We mentioned incidentally the fact that there is a loss that may be put into money values or labor values, caused by the work of insects that carry diseases to man, domestic animals, and cultivated plants. It will probably be well to say something more on these subjects, though it is impossible to make anything like an accurate estimate of losses through the carriage of diseases of man. I once wrote a bulletin on the subject in which I made an effort in this direction.[1] But that was twenty-one years ago. Conditions in certain respects have changed radically since those days, and especially since the latter part of the past century.

It is difficult to-day to realize the condi-

[1] Bulletin 78, Bureau of Entomology, U. S. Department of Agriculture, 1909.

tions that existed in earlier years in the United States with regard to yellow fever, a disease that is carried only through a certain mosquito. Northern cities were able, by rigid quarantine measures, to prevent serious epidemics after the early part of the nineteenth century, but from the West Indies and Central America the disease was occasionally introduced and prevailed from time to time epidemically in the Southern States. In 1853 it raged throughout this region, New Orleans alone having a mortal-



Male of the yellow-fever mosquito—*Aëdes aegypti*, L., with enlarged claw at lower right. (Author's illustration.)

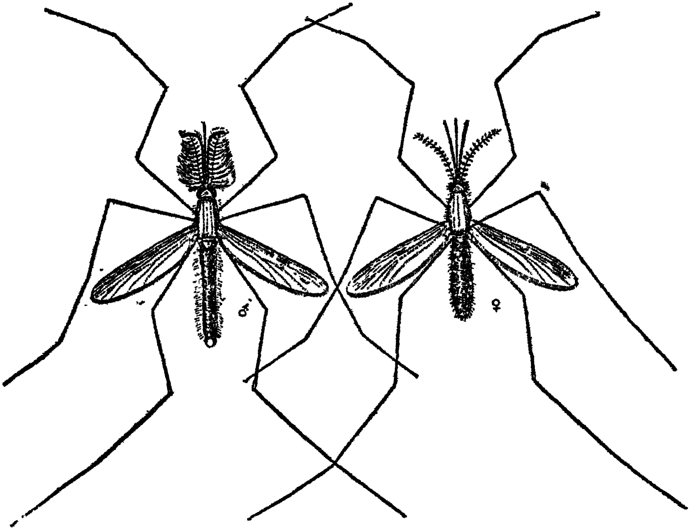
The female yellow-fever mosquito. (Author's illustration. U. S. Dept. Agriculture.)

ity of 8,000. The last widespread epidemic occurred in 1878, chiefly in Louisiana, Alabama, and Mississippi, but spreading up the Mississippi Valley as far as Cairo, Illinois, and attacking the city of Memphis, Tennessee. In this year there were 125,000 cases and 12,000 deaths. In 1882 there were 192 deaths at Pensacola; in 1887, 62 deaths in the Southern States; in 1893, 52; in 1897, 484 deaths; in 1898, 2,456 cases with 117 deaths; in 1903, 139 deaths were recorded, mostly at Laredo, Texas; and in 1905 there was a serious outbreak in New Orleans and in neighboring towns, including one locality in Mississippi in which 911 deaths were recorded.

The actual loss of life from yellow fever during all those years, when compared with the loss from other diseases was comparatively slight, but the death-rate was perhaps the most insignificant feature of the devastation which yellow-fever epidemics produced, and the disease itself was only a small part of the trouble which it brought to the Southern States. When the disease was once discovered in epidemic form the whole country became alarmed; commerce in the affected region was brought almost to a standstill; many cities were largely deserted; people died from exposure while camping out in the higher lands; rigid quarantines were established and innocent persons were shot while trying to pass the quarantine lines; nearly all industry ceased for the time.

The commerce of the South during the epidemic of 1878, for example, fell off 90 per cent. The hardships of the people cannot be estimated in monetary terms. With such industrial and commercial conditions existing from Texas to South Carolina, many industries of the North suffered; indeed, the effect of a yellow-fever summer in the South was felt not only all over the United States but in many other portions of the world. All these conditions, however, do not sum up the total loss to the national prosperity. Cities like Galveston, New Orleans, Mobile, Memphis, Jacksonville, and Charleston, subject to occasional epidemics, did not prosper as they should have done. Their progress was seriously impeded by this one cause, and thus the industrial development of the whole South was greatly retarded.

It will be possible to place the total money loss to be laid at the door of yellow-fever mosquito at an immense sum without danger of exaggeration. But all this is past, and in all probability another epidemic will never occur in the United States. Yellow fever has probably been wiped out, and there exist to-day, so far as the reports of the Public Health Service indicate,



The most important of the North American malaria-carrying mosquitoes—*Anopheles quadrimaculatus*. Note spots on the wings, and the long palpi, nearly as long as the beak. (Author's illustration. U. S. Dept. Agriculture.)

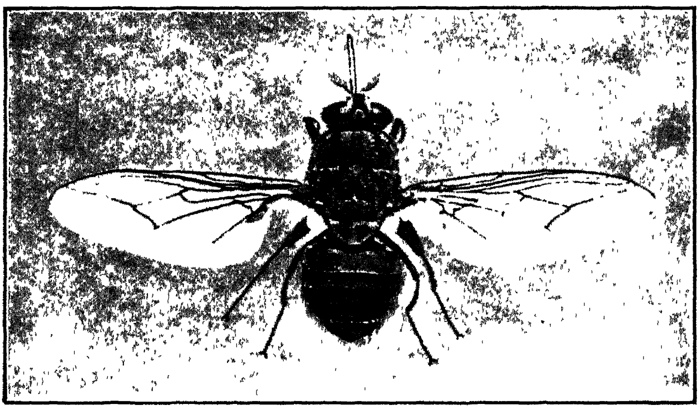
only perhaps half a dozen cases, in West Africa and Brazil.

Down to comparatively recent years, it would have been possible to estimate in stupendous figures the loss through typhoid fever (called enteric fever by the British) which under certain conditions was carried largely by the common house-fly as a mechanical carrier in its passage from exposed excreta to exposed food supply. While typhoid has not been wiped out, it is the source of infinitely less trouble to-day than it was even twenty years ago. Then, there is little doubt, the economic loss from the disease exceeded $100,000,000 a year in this country; but popular education, efficient work of citizens' committees and boards of health, and other factors, such as the disappearance of the horse in cities, have greatly lessened the numbers of house-flies, and the discovery of a successful method of inoculation against typhoid, used with marked success in the concentration camps during the World War, has reduced the disease to a very considerable extent.

For example, in the old registration States of the year 1900 the deaths from typhoid fell from 31.3 per 100,000 in 1900 to 2 in 1927, while in the registration States of 1910 (California, Colorado, Maryland, South Dakota, Pennsylvania, Washington, Wisconsin, Ohio, Minnesota, Montana, North Carolina, and Utah having been added) the death-rate fell from 22.5 in 1910 to 2.3 in 1927. But of course the death-rates alone are indicative of only a small part of the money loss and the labor loss. The incapacitation of hundreds of thousands of people for work and the necessary expenses brought about by illness amounted to huge sums.

At present, therefore, we need not consider yellow fever as the cause of money loss, and typhoid fever has sunk into comparative insignificance. There is another widespread disease,

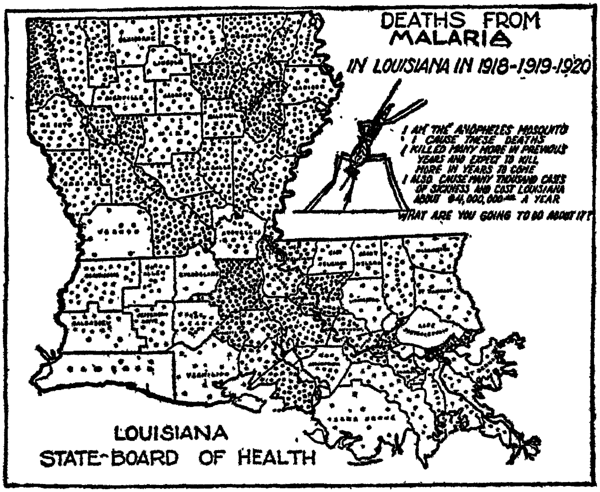
Statue by a famous Italian sculptor, symbolizing the effect of malaria on the population of the Roman campagna.



Tsetse-fly—*Glossina morsitans*—carrier of the sleeping sickness of Africa. (After Austen.)

however—malaria in its different forms—that is absolutely dependent upon certain species of mosquitoes; and there is no doubt that this disease not only is the cause of enormous loss of life and labor, but has actually influenced the progress of civilization at many times and in many ways.

The west coast of Africa, portions of India, and many other tropical countries were, down to a comparatively recent date, virtually uninhab-



MAP USED IN ANTI-MALARIA CAMPAIGN IN LOUISIANA

Each dot represents a death from malaria. The public-health importance of malaria, however, is more accurately measured by the sickness rate and the loss of efficiency than by the loss of life. It has been estimated that for each death 2,000 to 4,000 days of sickness must be included in the total burden of loss and suffering caused by the malaria mosquito.

itable by civilized man, on account of the presence of pernicious malaria. The industrial and agricultural development of Italy has been hindered to an incalculable degree by the prevalence of malaria in the southern half of the Italian peninsula as well as in the valley of the Po and elsewhere.[2]

The progressive physical degeneration of the ancient Greeks, one of the strongest races of the earth, is said by Sir Ronald Ross to have been caused partly if not largely by the introduction of malaria and its rather rapid spread.

It is not known whether malaria was endemic in the United States. It is supposed by some writers that it was the cause of the failure of the early colonies in Virginia. At all events, it made its early appearance, and it is certain that it retarded the advance of civilization over the North American continent in a marked degree. This was especially the case in the march of the pioneers throughout the Middle West and throughout the Gulf States west to the Mississippi and beyond. In many large regions once malarious the disease has been greatly reduced in

[2] In 1925, Professor G. Sanarelli, of the University of Rome, in a plea for the establishment of a national institute for malarial studies in Rome, made the following striking statement: "A malarial population is condemned to a state of organic, economic and civil inferiority. The question of southern countries is identical with the problem of malaria. Italy can never redeem herself economically and can never progress socially without first freeing herself from malaria."

frequency and virulence owing to the reclamation of swamp areas and the lessening of the number of the possible breeding-places of the malarial mosquitoes, but the disease is still very prevalent—especially so, perhaps, in the southern United States.

There are many communities and many regions in the North where malaria is unknown, but in a number of these Anopheles mosquitoes breed, and the absence of malaria means simply that malarial patients have not entered these localities at the proper time of the year to bring about a spread of the malady. It has happened again and again that in communities where malaria was previously unknown or in which it had disappeared many years earlier, it has suddenly made its appearance and has spread in a startling manner. Thus it happened once at Brookline, Massachusetts, that a rapid spread of the disease was started by the introduction of Italian laborers harboring the germs of malaria, to work upon a reservoir. With a rapidly increasing population, malaria still spreads in the United States in such ways.

To attempt an estimate of the economic loss from the presence of malaria in the United States is to attempt a most difficult task. Some years ago, in a paper read before an international tuberculosis congress, Professor Irving

Fisher declared that tuberculosis costs the people of the United States more than $1,000,000,000 each year. In his estimate he considered the death-rate, the loss of the earning capacity of the patients, the period of invalidism, the amount of money expended in the care of the sick, and other factors. With tuberculosis one has a much more definite basis than with malaria.

The death-rate from malaria (as malaria) is comparatively small and it has been decreasing during the last twenty years. In 1909 I showed that from a table comprising twenty-two cities it appeared that two thirds of the deaths from that cause in the United States occurred in the South—one third only in the North. I figured out that the death-rate from malaria for the whole United States probably amounted to 15 per 100,000. That gave at that time an annual death-rate of about 12,000.

The popularization of knowledge regarding the disease and the admirable work done by the United States Public Health Service in assisting communities, especially in the Southern States, to carry on relief and control measures have constantly been reducing the malaria rate since that time. I have been consulting the mortality statistics prepared by the Bureau of the Census for 1927, and I find that in the registration area of 1910 the death-rate was reduced from 1.1 per

100,000 in that year to 0.1 per 100,000 for 1927; but it must be remembered that even in 1910 a number of the most malarious States had not qualified for registration. These included such States as Kentucky, Missouri, Virginia, the Carolinas, Tennessee, Louisiana, Florida, Mississippi, Georgia, Alabama, and Arkansas, all of which are known to contain very malarious sections. Morover, the health reports come in to the Public Health Service and the Census from the cities, and malaria is rather distinctively a country disease. So that the death-rate for the country as a whole must be very far greater than that mentioned.

But with malaria, perhaps as with no other disease, the death-rate fails to indicate the real loss from the economic point of view. A man may suffer from the disease during the greater part of his life, and his productive capacity may be reduced from 50 to 75 per cent, and yet ultimately he may die from some entirely different immediate cause. In fact, the predisposition to death from other causes that is brought about by malaria is so marked that if, in the collection of vital statistics, it were possible to ascribe to it its real influence, the disease would have a very high rank in mortality tables. Once, in writing of tropical countries, Sir Patrick Manson declared that malaria causes more deaths and more predisposition to death by inducing cachectic states leading to other affections than all the other parasites affecting mankind put together. Also it has been shown that the average life of the worker in malarious localities is shorter and that the infant mortality is higher than in healthy places.

If the lessening or destroying of the productive capacity of the individual is of importance, the same result on the population of a malarious region is enormous, even under modern conditions and in the United States. It is said that the depopulation of the once thickly settled Roman Campagna was due to the sudden introduction of malaria by the mercenaries of Sulla and Marius. Celli in 1900 stated that owing to this disease about five million acres of land remained in Italy under imperfect cultivation. The cases of the islands of Mauritius and Réunion might also be mentioned, since in comparatively recent years malaria was accidentally introduced, with the result that the productiveness of these rich colonies was virtually destroyed for a time. Dr. R. G. Eccles, in an article published in the "Medical Record" (New York, January 16, 1909), called attention to the article on malaria by Creighton in the Encyclopædia Britannica in which it was stated that the disease "has been estimated to produce one-half of the entire mortality of the human race, and, inasmuch as it is the most frequent cause of sickness and death in those parts of the world most densely populated, the estimate may be taken as at least rhetorically correct."

In my 1909 paper I showed that Celli in 1900 estimated the number of cases of malaria for Italy per year at about 2,000,000, and upon Celli's methods I estimated approximately the number of cases in the United States at about 1,550,000. Since Celli's estimate was made on the basis of hospital patients only, I expressed the opinion that the number of Italian cases would possibly reach 3,000,000.

As a rule malaria in the United States is of a lighter type than that in Italy, but I am told by physicians that it will not be an exaggeration to estimate that one fourth of the productive capacity of an individual suffering with an average case is lost. Altogether I placed the annual loss from this disease in the United States at $100,000,000. Nowadays the cost of operations against mosquitoes and malaria, including extensive drainage measures, must be charged to the mosquito account.

More and more of this work is sure to be done. Certain regions containing most fertile soil and capable of the highest agricultural productiveness have been virtually abandoned. In the absence of malaria they would have added millions upon millions to the wealth of the country. In 1909 the United States had already initiated large-scale drainage measures, and parties of engineers were being sent by the Government to make preliminary drainage surveys in the most prominent of the potentially productive regions. Dr. George Otis Smith, Director of the United States Geological Survey, once told me of the effect of malaria on the progress of this work. He said:

"In one of the Southern States eleven topographic parties have been at work during the past field season. The full quota for these parties would be fifty-five men, but I believe that something over one hundred men have been employed at different times during the season. While I have not exact figures before me, I feel warranted in the statement that at least ninety-five per cent of these employees have been sick, for periods ranging from a few days up to two weeks, in the hospital. Many of them have been able later to return to work, but at least thirty per cent had to leave the field permanently. By reason of this sickness the efficiency of the parties was reduced, at a very conservative estimate, by twenty-five per cent.

"In my recent visit in this field I found one man sick in each of the parties I saw and one man who had just returned from the hospital leaving the field for good. A similar state of things was reported from the other parties. I regard the sickness as practically all of a malarial nature, as extreme care was taken in all the camps to use nothing but boiled water except in a few instances where artesian water from great depths was available. In all the camps the tents have been screened, and in every case where the topographer has lived for any time 'on the country' there has been infection."

In considering Dr. Smith's statement, it must be borne in mind that the men of his field parties were exceptionally intelligent, and prepared to take all ordinary precautions.[3]

Throughout the region in question malaria is almost universal. The railroads suffer, and at the stations throughout the territory it is virtually impossible to keep operators steadily at work. Moreover, reduction in efficiency in the surveying parties and in the local railroad officials is, probably, considerably less than the reduction in the earning capacity of the entire population, which, however, is necessarily scanty.

[3] It is interesting to note that quite recently (Mch. 6, 1931) the U. S. Public Health reports give an account of an outbreak of malaria in a railroad camp in California where Mexican labor was employed. Out of a force of thirty, twenty-two were attacked and more or less incapacitated for the hard work required.

In 1903, Professor Glenn W. Herrick, then of the Agricultural College of Mississippi and later of Cornell University, published a forceful article in the "Popular Science Monthly" for April. It is especially apt in this connection, and the following paragraph is quoted from it:

> We must now consider briefly what 635,000 or a million cases of chills and fevers in one year mean. It is a self-evident truth that it means well for the physicians. But for laboring men it means an immense loss of their time together with the doctors' fees in many instances. If members of their families other than themselves be affected, it may also mean a loss of time together with the doctors' fees. For the employer it means the loss of labor at a time perhaps when it would be of greatest value. If it does not mean the actual loss of labor to the employer it will mean a loss in the efficiency of his labor. To the farmers it may mean the loss of their crops by want of cultivation. It will always mean the non-cultivation or imperfect cultivation of thousands of acres of valuable land. It means a listless activity in the world's work that counts mightily against the wealth-producing power of the people. Finally it means from two to five million or more days of sickness with all its attendant distress, pain of body, and mental depression to some unfortunate individuals of those five States.

In the same article Professor Herrick said that the delta region in Mississippi was the second-best farming land in the world, being inferior only to the valley of the Nile. At that time much of the land could be bought for from ten to twenty dollars an acre. The reason why thousands of people did not settle there was on account of the chills and fever to which they would be subject. He prophesied that when malaria in the delta should be overcome, that region would be the richest and most populous in the United States.

Since the days when Professor Herrick wrote this impressive article a vast deal of anti-malaria work has been done in the South. Herrick's successor, Professor R. W. Harned, delivered an address before the Association of Economic Entomologists in 1927 indicating that there had been a great change in the intervening years. He said that at the Mississippi Agricultural and Mechanical College twenty years before the hospital would be crowded with students from the delta section of the State who were suffering from malaria, whereas in 1927 for several years the college physician had not had to treat a single serious case of it. He went on to say:

The Anopheles mosquitoes and malaria are being reduced from year to year. Where a generation ago they went unchecked, a new agricultural empire is developing in a region with soil as fertile as any on this continent, and where health conditions are now above the average and are improving constantly. Sunflower County, Mississippi, in the center of the Yazoo-Mississippi delta, was twenty years ago teeming with mosquitoes and malaria, yet in 1923 and 1924 girls from this county won the National Health Contest in Chicago in competition with the healthiest girls from all parts of the country, and the 1926 girl from that county tied for the first place with an Iowa girl. Could this have happened twenty years ago?

The people who study the diseases of plants are known as phytopathologists, and their science is called phytopathology. In Europe the term is used to cover all plant enemies, including insects, but, as the word itself means plant disease, the European use would apply to insects as diseases of plants. This seems rather absurd to us, since by the same reasoning a cow that eats grass would be considered as a grass disease. But the phytopathologists discovered several years ago that some of these diseases are carried by certain insects in much the same way that some diseases of man are carried. So far, I believe there has been no contention that insects are necessary secondary hosts and that the organism has to undergo a development in the body of the insect before it can be transmitted from one plant to another; but that they act as mechanical carriers of a number of serious diseases has been proved beyond all question. How much further such discoveries will go, we cannot say.

It becomes important, therefore, in attempting to estimate the loss that the human species suffers through insects, to know something about plant diseases. There is the same difficulty, in reckoning the loss in dollars and cents or in quantity, that there is in the case of real insect enemies; but vigorous efforts have been made by the men working in that field, and for years the Bureau of Plant Industry of the United States Department of Agriculture, with the aid of the State Agricultural Colleges and Experiment Stations, has been collecting records of the losses in some of the more valuable crops. Of course no method exists for exact measurement, but the figures reached represent the combined judgment of the workers of the country, and are probably approximately correct. It will be unnecessary to go into detail here, but it should be stated that the total estimate of losses approximates $1,500,000,000 annually. The workers have drawn up tables by crops, and in 1926 showed that these losses for the previous six years varied from 1.78 per cent of the rye crop to as much as 22.24 per cent of the sweet-potato crop; wheat losing over 10 per cent, peaches 11 per cent, apples 14 per cent, cotton 13 per cent, Irish potatoes 19 per cent. Variations from year to year in these losses are by no means constant, and weather factors exert a decided influence.

What part insects play in the spreading of plant diseases cannot be expressed at all exactly. We know that they are of extreme consequence with respect to two destructive ones—the mosaic disease of sugar-cane and the so-called curly-top disease of sugar-beets. As to other diseases of lesser monetary importance, there is less evidence. There seems to have been no general summary in late years. As early as 1920 the literature on plant diseases transmitted by insects was already fairly extensive, and the menace of insects as spreading agents was said at that time to be becoming greater every year. Dr. F. V. Rand and W. D. Pierce, in an article published in 1920, stated that the investigations of the preceding three decades had completely revolutionized our view of the rôle of insect transmission in both plant and animal diseases.

From the early work of M. B. Waite, for example, it was decided that the fire-blight of pear and other allied fruit-trees was caused by a certain bacillus that is transmitted by insects such as plant-lice, bark-borers, and others. A bacterial wilt of potatoes and other plants of that family was found to be transmitted by various insects. A blight of oats, and a bacterial rot of lettuce, and a bean mildew were found to be insect-transmitted. And then opened up a wide range of plant diseases. Dr. W. A. Taylor, Chief of the Bureau of Plant Industry of the United States Department of Agriculture, has shown me a bibliography of articles published since 1920 on the insect transmission of plant diseases. This bibliography, compiled by Dr. N. E. Stevens, lists nearly one hundred and sixty articles, and the papers in the long list include consideration of the diseases of many important crops.

The subject is an exceedingly live one to-day, and it is such a comparatively new field of investigation that we cannot safely prophesy the extent to which it may be proved that indirect damage by insect transmission is of enormous consequence.[4]

We have seen that the phytopathologists estimate a loss of $1,500,000,000 from plant diseases. No one would dare to say what part of this can be attributed indirectly to insects, but it is undoubtedly sufficiently large to score a big black mark against them.

[4] The latest announcement of the transfer of a destructive plant disease by an insect that has come to my eye appears in the journal "Science" for March 6, 1931. Mr. Maurice B. Linford, of the University of Ohio, announces that the dangerous and destructive yellow-spot disease of pineapples is transmitted by a little insect known as *Thrips tabaci.*

It is a decided let-down to spend time considering insects as mere nuisances when we have just shown how they threaten to drive us to starvation by destroying our food and how they endanger our very lives by the diseases they carry; but simply as a cause of infinite annoyance they are of such moment that we must talk about it.

Among the ten plagues of Egypt, three were insect plagues, namely, the lice and the flies and the locusts. It is true that lice and flies carry disease, but no one knew that until recently, and they have always seemed to human beings just filthy pests. And as for the locusts, they need not be considered here, since the result of the swarms that came in from the east was destruction of vegetation.[5] But imagine the dust of the earth transformed into lice! While it transcends what any of us have seen, some of the soldiers who lived in the trenches at the front for many weeks during the World War will be able to testify that lice are serious blots on that kind of life. Under peace conditions, however, the world has grown much more cleanly, and even in great armies sanitation will constantly improve.

In the tropics certain insects become personal annoyances to an extent that it is difficult for one

[5] A somewhat irreverent Egyptian friend, in writing of the recent locust outbreaks in Egypt, refers to the Biblical incident as "the locust plague that Moses engineered on behalf of the Lord."

living in temperate regions to realize. Humboldt, who often wrote very picturesquely, has told us about mosquitoes and other biting flies in South America, especially on the Orinoco. He says, for example:

> Persons who have not sailed upon the great rivers of equinoctial America, the Orinoco for example, or the Magdalena, cannot conceive that at every moment without interruption one can be tormented by the insects swarming in the air, and the number of these little animals can render vast regions almost uninhabitable. One can never become accustomed there to stand the bites without complaint.

In another paragraph he writes, "The lower layers of the air, from the earth up to fifteen or twenty feet in height, are filled with venomous insects like a condensed vapor," and elsewhere he mentions "the insufferable torment of flies." Again:

> At Mandavaca we found an old missionary who told us with an air of sadness that he had passed *twenty years of mosquitoes* in America. He told us to look at his legs in order that we might be able to tell the people some day across the sea what the poor monk suffers in the forests of the Cassiquiare. As each bite leaves a little brownish black spot, his legs were so speckled that one could with difficulty see the whiteness of his skin between the spots of coagulated blood.

To quote from him once more:

> In the midst of a country where they are ignorant of what is going on in the rest of the world, this [the size and ferocity of mosquitoes on different parts of the same river] is the favorite subject of conversation. "How sorry I am for you!" the missionary of the Raudales on our departure said to the missionary of the Cassiquiare. "You are alone just as I am in this country of tigers and apes; fishes where I live are rarer than here; the heat here is greater, but as to the flies I can boast that with one of mine I can beat three of yours!"

There is an old story told by Kirby and Spence to the effect that in the neighborhood of the Crimea the Russian soldiers were obliged to sleep in sacks to defend themselves from the mosquitoes; and this was not sufficient, for several of them died in consequence of the bites of the ferocious bloodsuckers.

And even away from the tropics and away from the Crimea of the older days, there are few regions of the habitable globe where man is not personally subject to annoyance by insects. In this part of the world we naturally think at once of mosquitoes, house-flies, and fleas. Thirty or forty years ago a susceptible individual wrote to the United States Department of Agriculture and said he had come over from the old country and settled in New Jersey, but the mosquitoes bothered him so that on the advice of friends he moved to northern New York. Here he found that during a certain portion of the year black-flies made life unendurable; thereupon he packed up his household effects and moved to North Carolina. Here, however, in the summer months red-bugs, or jiggers, were such a trial that he actually feared he would go crazy. In desperation he applied to the department to learn whether there existed in the United States a locality where a sensitive individual could find peace from the attacks of insects. He said he had been told that in the Western country the buffalo-gnat was greatly to be feared, while certain other biting flies would be there to worry him, and that in the South peaceful nights were to be gained in the summertime only under the protection of mosquito-bars. He had thought of the newly developing country of Alaska, but had recently seen an account in the newspaper of the ferocity of the Alaskan mosquitoes, which had deprived him of his last hope.

We know now to what an extent all of these pests may be controlled, and if their control is not attempted it is through ignorance, indifference, or lack of funds. But in the tropics conditions are still bad. In most warmer countries the comfort of the individual absolutely depends upon the adoption of measures, always difficult and frequently impracticable, to exclude insects from his person and from his food. Fairly common conditions are so naïvely described by "A Poet of the Indies" that we copy it from Kirby and Spence:

On every dish the booming beetle falls,
The cockroach plays, or caterpillar crawls:
A thousand shapes of variegated hues
Parade the table and inspect the stews.
To living walls the swarming hundreds stick,
Or court, a dainty meal, the oily wick;
Heaps over heaps their slimy bodies drench,
Out go the lamps with suffocating stench.
When hideous insects every plate defile,
The laugh how empty, and how forced the smile!

In more temperate regions those mosquitoes that do not carry disease frequently become of prime importance because of their mere numbers and their irritating bites, and in cases of weak or sick persons they have often brought about a nervous condition with disastrous results. The mere expense of screening against them becomes a matter of considerable importance. Only a few years ago the United States used thirty millions of dollars' worth of wire screening *in the roll* to protect houses against mosquitoes and flies. This amount must increase year by year, and the expense of placing screens in operation must nearly double that of the original cost of the wire netting.

In the past, mosquitoes have rendered virtually uninhabitable many localities which would have been desirable as homes and would have offered decided advantages for intensive agriculture and for manufacturing had it not been for the presence of these pests. Since anti-mosquito work on a large scale began, early in the present century, a number of such regions have been relieved of the nuisance.

The State of New Jersey, and particularly its ocean-front, bordered by miles of salt-marsh, was for years held back in its development. "The New Jersey mosquito" was notorious. Despite this drawback, however, the State became well settled, and, on account of its geographic location and other natural advantages, thrived. Early in this century, with commendable energy and foresight, the State passed laws which have brought about a large-scale and measurably successful effort to reduce the mosquito nuisance. Large sums of money have been expended in the fight, but the result has been that extensive areas of valuable land have been redeemed, regions have been opened up for habitation, the taxable value of much territory has been greatly increased, and the State has set a splendid example to the rest of the world. An association has been formed, called the New Jersey Mosquito Extermination Association, whose annual meetings at Atlantic City have become famous in a way. Delegates are sent to these meetings from many parts of the United States, and the papers and discussions are published annually.

As for the house-fly, aside from the fact that it is a mechanical carrier of the germs of several usually fatal diseases, as a mere pest in numbers and persistence it cannot be overestimated. It is true that there has been an enormous reduction of house-flies, yet they still abound in some localities. Not so very long ago Dr. Theobald Smith observed: "When we go into public restaurants in midsummer we are compelled to fight for our food with the myriads of house-flies which we find there, alert, persistent, and invincible," and even though their numbers are so reduced, still it seems to some of us that the flies that are left are often excruciatingly annoying. I think that a sympathetic chord will be touched in many of us by a newspaper paragraph that comes to my eye as I reach this:

> One reclines for a nap, or picks up a book for a quiet hour or two of absorption in things remote from the day's cares, but no sooner has one settled down in ease and comfort than comes one solitary fly left buzzing alone. He craves human companion-

ship. He becomes affectionate. Shooed away, he returns, again and again. Finally, the exasperated human hunts up the discarded fly-swatter, swats a swat or two, and the last lonely fly has received his quietus.

So it seems today. But tomorrow it is different. Again comes the solitary fly, from one knows not whence, and the same procedure is gone through.

More than twenty years ago I helped in a crusade against the house-fly, and in the course of an article I wrote at that time I find two widely separated paragraphs that have been quoted by Doane in his admirable little book called "Insects and Disease" [6] as well as by others, and that I think might be repeated here. The first one is:

Even if the typhoid or house fly were a creature difficult to destroy, the general failure on the part of communities to make any efforts whatever to reduce its numbers could properly be termed criminal neglect; but since, as will be shown, it is comparatively an easy matter to do away with the plague of flies, this neglect becomes an evidence of ignorance or of a carelessness in regard to disease-producing filth which to the informed mind constitutes a serious blot on civilized methods of life.

The second:

A leading editorial in an afternoon paper of the city of Washington, of October 20, 1908, bears the heading, "Typhoid a National Scourge," arguing

[6] Henry Holt & Co., 1910.

that it is to-day as great a scourge as tuberculosis. The editorial writer might equally well have used the heading "Typhoid a National Reproach," or perhaps even "Typhoid a National Crime," since it is an absolutely preventable disease. And as for the typhoid fly, that a creature born in indescribable filth and absolutely swarming with disease germs should practically be invited to multiply unchecked, even in great centers of population, is surely nothing less than criminal.

It will be shown in a later section that the insects that tend to increase destructively have no more effective natural enemies than other insects, and in that section is shown how we are taking advantage of this fact. It must be understood that in speaking of the insect menace we are speaking only of the insects that are harmful to the interests of humanity. The human race has many friends among the insects. Not only do they furnish the most effective enemies of injurious species, but the great, world-wide honey industry is dependent upon the domestic honeybee; until very recently, all of our silk goods came initially from the domestic silkworm; and in times past the lac industry and others such as the manufacture of ink and tanning mixtures from insect galls, and dyestuffs from scale-insects have added to the debt owed by the human race to certain insects.

All of these, however, seem trifling compared with the fact that the useful and ornamental vegetation of the world would dwindle to insignificance were it not for the fertilization and cross-fertilization of flowers by insects. Without the aid of insects various kinds of agriculture and horticulture would almost come to a standstill. And then, of course, insects are food for domestic poultry, for birds, and for many kinds of food-fishes. If we were to sum it all up we should find that we are tremendously indebted to the insect class. This fact naturally does not influence us in the least in our attitude toward the destructive species, yet it should be mentioned here.

I was much amused recently by an article published in a Vienna newspaper, written by Franz Maidl, a most competent entomologist, who is a custodian in the great Vienna Natural History Museum. In this article Maidl is probably writing more or less ironically, but his title is "Our Planet with No Insects—A Catastrophe which We Hope Will Never Occur." He sums up the benefits that we have just referred to, and suggests, supposititiously, that, after the matter had been considered in the United States, a method of controlling all insects might have been found, as, for example, a substance which would be readily eaten by them and which would cause them to cease to propagate. He pictures the result. The men whose living had been derived from the bee industry, or the silk industry, or any of the other industries based upon insects, would be jobless; the surface of the earth would be covered with the bodies of birds that had died from starvation, since there had been no insects for them to eat; other animals, such as hedgehogs, moles, shrews, many reptiles, and such amphibians as frogs and toads would die; orchards and gardens and farms would dwindle rapidly from lack of cross-fertilization by insects; the jobless persons would be put to work to fertilize the plants with small brushes, but such persons would be absurdly insufficient in number. A single honey-bee would visit four thousand blossoms a day, and it appears that Germany, with 2,750,000 beehives each having 10,000 worker bees, each bee making forty trips a day and visiting one hundred blossoms each trip, would have eleven trillion flowers visited daily by fertilizing worker bees. This is a job that humans could not duplicate.

Herr Maidl's conclusion, after the consideration of this hypothetical occurrence, is expressed in the following words (translated): "The destruction of insects, indeed, was the silliest trick which humanity committed during the twentieth century." His article is an interesting one, but

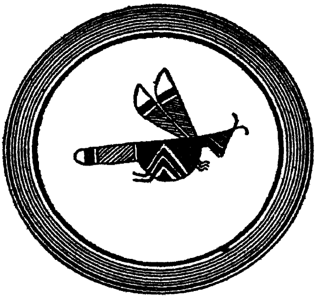
I am rather sorry he wrote it, for the simple reason that, although we are preaching the destruction of injurious insects and stimulating the fight against them as much as possible, no one, even in America, has ever said a word about destroying beneficial species.

I have just completed a history of applied entomology in which I have briefly traced the growth of man's rather puerile struggle against the insects. Wherever a center of human civilization had its beginnings, it is quite certain that just as soon as a food-plant began to be grown on a sufficient scale to feed many people, certain insects took advantage of the situation and began to increase in number rapidly. The insects were there long before man, and if he increased their food supply, naturally they increased. The human species encouraged them, therefore, and was responsible for their increase.

The beginnings of history have recorded occasional significant things about insect outbreaks, especially the disasters caused by migratory locusts. There is no doubt that famine and disease have followed great locust flights since man began to depend upon agriculture; and even before that, during his existence simply as a hunter, it is fair to suppose, locust plagues, by destroying the food of the animals he hunted, had an effect upon his welfare. I have hazarded the guess that locusts have been in some degree the causes of the migrations of nations, and possibly in certain cases have helped in the destruction of civilizations.

The first detailed reference to a locust invasion in well-known literature is that given in the Old Testament (Exodus X, 13–15). And the locust swarms that occasionally invade the Holy Land and Transjordania and Egypt even to to-day might well be described in the words of the Bible writers. Invariably they come from the east, just as they did in the time of Moses. Mr. H. C. Efflatoun states that an excellent carving of a locust that he thinks may be *Schistocerca peregrina* has been found on the walls of a tomb at Thebes of the date, probably, of 1400 B. C.

Among the records of much later but comparatively early times, several relating to Cyprus have been brought together in a "Handbook of Cyprus," by Luke and Jardine. Among other things, it is stated that during the reign of Hugh I, a Lusignan King of Cyprus, the icons of Saints Christopher, Tarasins, and Tryphon were carried processionally to meet the advancing swarms, and the crops were saved. In 1628, Archbishop Christodoulos begged the abbot of "the Laura on Mount Athos" to send him the



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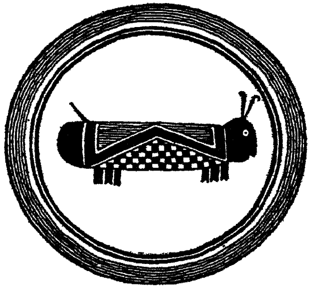

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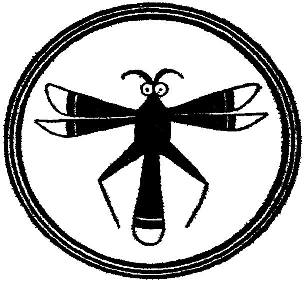


98

Designs of insects from pre-Columbian Central American pottery. Reproduced from Vol. 74, Smithsonian Miscellaneous Collections. Figs. 93, 94, and 96 are obviously grasshoppers; 98 is supposed to be a dragon-fly; 95 and 97 are uncertain.

head of Saint Michael to stay the plague of locusts.

Mr. C. G. Pelaghias, in a recent bulletin published by the Cyprus Department of Agriculture, states that in 1411 a priest was suffocated by locusts.[7]

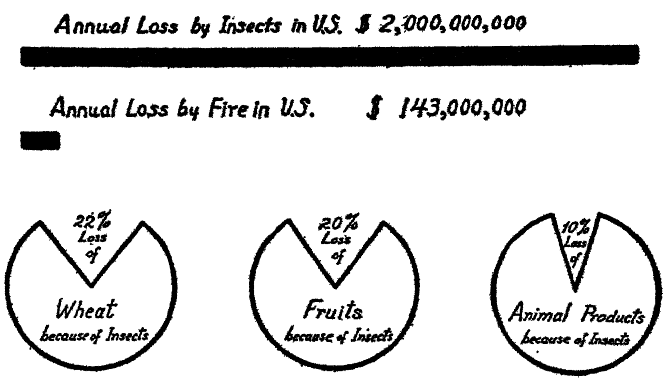
There are occasional traces of man's knowledge of insects even in prehistoric times. The late J. Walter Fewkes told me that he was interested in undoubted representations of insects by the Mayas in Central America. And in 1928 L. Chopard of Paris showed the Entomological Society of France a photograph of the fragment of a bison bone found by Count Begouen in the cavern known as Trois-Frères (Ariège). On this bone was engraved a grasshopper, with several drawings of birls. It was of the Magdalene period, and M. Chopard, who is a well-known orthopterist, believes that it was intended to represent one of the cave-inhabiting forms near the genus *Troglophilus.* The full account will be found in the "Comptes Rendus de la Société Biogéographique," Volume XLI, pages 64–66.

But in the history of the development of modern civilization in Europe it has not been pointed out that insects have played a very de-

[7] This would seem to indicate an especial warfare between the Church and the locusts.

structive part. There has never been the kind of agriculture that especially encourages insect plagues. Constant wars, plague epidemics, typhus, and other causes have prevented rapid increases of population, and the loss through insects, except occasionally, was probably not excessive and was unappreciated. Then, too, it was wholly unknown that two of the greatest causes of the restriction of the population—namely the plague and typhus—are insect-borne diseases. No one knew how much of a crop was destroyed by the minute insects that could hardly be seen, and a particular space of land was supposed to grow a certain amount of wheat, and so on.

Thus it was not until new countries were



Diagrams indicating the great economic waste caused by a few injurious kinds of insects. The figures are, of course, based on estimates and they vary from year to year.

opened up to settlement on a large scale that crop-destroying insects were given their great chance to multiply. This occurred first, so far as history goes, in North America, later in South Africa, Australia, New Zealand, and other British colonies and dominions. It has happened everywhere. Russia, as its large-scale agriculture spread to the east, gave insects the same chance.

Of course, in all new countries, although the introduction of agriculture began on a comparatively small scale, it increased rapidly with the growth of settlement, and the upsetting of the balance of nature brought about abnormal conditions with very bad results. In the United States the large grain-fields began to suffer from the Hessian fly and the chinch-bug, the cotton-fields from the cotton caterpillar, the orchards from the codling-moth and the plum-curculio, and so on.

In this enlightened country there is comparatively little evidence of superstition, and although occasional insect plagues have been more or less indefinitely attributed to a visitation of Providence, there have been neither here nor in the English colonies any efforts directed toward the pacification of the "wrath of God." In fact, I recall only two incidents verging on this method so often used in former times in other countries, as, for example, we pointed out in the

The old-time idea of an entomologist. From a painting by A. Bodenmüller, 1872.

case of Cyprus in an earlier paragraph of this section. One of these incidents that I have in mind was in Louisiana in 1804: A Father St. Pierre was most earnestly entreated by his parishioners to furnish holy water with which to repel cotton caterpillars. The other was in 1875, when the Governor of Missouri appointed a day of fasting and prayer on account of the ravages of the Rocky Mountain locust.

After all, the people of the old days were not to be blamed for their comparative lack of interest in the insect question from the economic point of view, for with the multiplication of injurious species the damage that they have brought about has become enormously greater and more rapid as the years have gone by. Populations have been growing extraordinarily and the food demands have of course kept pace, and the food has been produced naturally, in the quickest and easiest ways. It happens that these ways have been wonderfully favorable to the insects. And not only has commerce between countries grown but the rapidity of land journeys and ocean crossings has very greatly increased, so that injurious insects have been carried from countries where they originated to other countries that had not known them previously.

So, we see that the appreciation of the insect menace is necessarily one that has come about only in comparatively late years. It is a fact difficult to realize that between 1771 and the outbreak of the Civil War in 1861 there were only twenty-three writers in North America who published worth-while notes or articles on injurious insects. During the same period in Canada there were only two such writers. Fifty-five years ago there were not ten men in the whole world who were devoting their entire time to this subject. Fifty-three years ago, when I came to Washington, D. C., the Government's entomological service consisted of three persons.

About the same time that Kirby and Spence wrote, an edition of the Oxford Encyclopædia was published (in 1828). I have not seen the encyclopædia, but Mr. H. J. Carter of Australia writes me that the state of public opinion at that time was there expressed in these words: "There is not perhaps any branch of natural history the study of which has been so generally regarded with indifference and contempt. The insect hunter is not infrequently treated with ridicule and his pursuit branded as frivolous."

The world of humanity has not only been indifferent in former years, but entomologists have been ridiculed in song, story, on the stage and in everyday life. The study of entomology in all of its phases has been thought a ludicrous, trivial pursuit. There is no doubt that many men have been affected by these almost universal ideas, and that without such ideas the study of entomology would have been much further advanced. One hundred and fifty years ago the will of Lady Glanville was contested on the ground that she was insane, since she had a collection of butterflies. And in comparatively recent times a naval officer in Australia who was also a distinguished entomologist was thought to be of unsound mind—because of his entomological pursuits. A hundred years ago Kirby and Spence wrote of entomology as "a science which in nine companies out of ten with which he may be associated promises to signalize him only as an object of pity and contempt." The same writers ask, "How can he look for sympathy in a pursuit unknown to the world except as indicative of littleness of mind?"

This popular attitude has undoubtedly had a very bad effect on the progress of the science. In my younger days I felt it keenly. Others of my contemporaries among the entomologists have suffered with me. "Suffered" is too strong a word, of course, but those of us who stayed by the study of insects must have had a most unusual mental composition, since none of us were led by this popular estimate to what is nowadays called an "inferiority complex."

One of the latest and most striking instances in which this widespread popular opinion of entomology is shown to have affected highly placed and otherwise undoubtedly intelligent and even intellectual people occurred during the World War. No less a person than the Speaker of the House of Commons in the English Parliament, Mr. Lowther, wrote a letter to the "London Times," that was printed in that newspaper for February 2, 1916, on page 9, about the proposed closing of the museums in London. He argued that the saving would be small, but that the released members of the staffs could be employed to much better advantage than by "deciphering hieroglyphics or cataloguing Microlepidoptera." Of course, I think that he was right about the hieroglyphics, but as to the Microlepidoptera, it so happens that the grain foods sent to the troops in France and received in London from England's foreign dominions were subject to disastrous damage from the larvæ of certain of these same Microlepidoptera. That some one continued at the museum studying these creatures (as did the late J. Hartley Durrant) resulted undoubtedly in much good for Great Britain; and Mr. Lowther, as we say in the American language, "made a bad break."

Sir Arthur Shipley, in his little book entitled

"More Minor Horrors,"[8] which was published as a supplement to his volume entitled "The Minor Horrors of the War," in a foot-note on page 116 comments thus on the incident:

> The Speaker's sneer at the entomologists who work at this group (see his letter in *The Times* of February 2, 1916) is hardly worthy of one of the chief trustees of the British Museum. As a chief trustee, he must have been aware of the exhibit of the Microlepidoptera, *E. kühniella,* and its devastating action on the biscuits supplied to our soldiers by the War Office, which has for many months occupied a prominent position in the middle of the central hall of the Natural History Museum at South Kensington. This exhibit showed how closely the study of the Microlepidoptera is associated with the food supply of our soldiers in many parts of the world.

[8] Smith, Elder & Co., London, 1916.

Chapter VII

THE WORLD IS WAKING UP

WE ARE awakening from our apathy concerning the insect menace! At the present time in the United States (which, by the way, is said to lead the world in its appreciation of the importance of this branch of applied science) there are now many hundreds of trained scientific men and women who are devoting their lives to the study of insects, in the effort to find the best means of controlling them. In the Bureau of Entomology of the Department of Agriculture at Washington there are nearly five hundred such people. Every State in the Union has its Agricultural Experiment Station in which is a corps of workers of this class.

All of the agricultural colleges and some of the universities have teachers who are training young men.[1] California has county entomologists and a few cities, like Philadelphia, have city entomologists. Recently a few well-trained men have branched out into private practice as consulting entomologists. The American Asso-

[1] To indicate the diversified character of this teaching it may be mentioned that Professor J. J. Davis, of Purdue University, among other courses is giving one on "Entomology for Pharmacists."

ciation of Economic Entomologists has more than a thousand members.

Other nations have felt the same impetus, though not as yet to the same degree. Of course there are reasons why the loss to crops in the smaller and more densely populated countries of Europe has not been so great through insect attack as in the comparatively recently settled areas of the United States. Over there the holdings are much smaller, the cultivation is more intense, labor has been cheaper, and they have not felt the same need of efforts to prevent serious economic losses. Just before the outbreak of the World War, however, Russia had a very promising service; all through the agricultural districts there were stations where scientific men, skilled in the study of insects, were engaged in research. Since the war this work has been resumed and is now well organized. Since the war, moreover, other European countries have had their interest aroused to the subject of insect damage. France, for example, has now enlarged her service and there are stations scattered over the country where research is going on. Italy, Spain, and other countries have joined in the movement.

In many of the dominions and colonies of Great Britain the insect problem is almost if not quite as great as it is in the United States. As a result, Canada has developed an important service, now employing more than sixty entomologists. The congress of Indian Entomologists held at Pusa, India, almost every year is attended by a large group of interested workers. The South African Federation and the Australian Federation employ a number of official entomologists, and at the new Australian capital at Canberra competent laboratory buildings are being constructed. There are trained men stationed in colonies like British East Africa, Uganda, British Guiana, Trinidad, the Fiji Islands, and others.

Moreover, Great Britain has established an Imperial Institute of Entomology with headquarters at London, to the support of which not only the British Government but also the Governments of the dominions and colonies contribute. This forms a rallying-point for all of the practical entomologists in the British dominions. To the great British Museum of Natural History as a center, they send all of their new specimens of injurious and of beneficial insects for identification, and the institute publishes, for the benefit of British workers—and in fact the rest of the world as well—two important journals that print monthly competent reviews of all of the publications relating to agricultural and medical and veterinary entomology, wherever published and in no matter what language.

Backed by appropriations from the Empire

Marketing Board, the Imperial Institute established recently a field station at Farnham Royal (Bucks), where studies are being made of insects that may be used in bringing about parasitic control of pests, and where these insects may be reared in large numbers and sent to the dominions or colonies that need them. The director of this laboratory at the present time is Dr. W. R. Thompson, a Canadian, who spent many years in the service of the Bureau of Entomology of the United States.

One of the important steps in the world-wide development of interest in the war against the insects, even before the outbreak of the World War, was the establishment of the so-called Carnegie Scholarships in practical entomology. It makes a very interesting story that has never been told in full. It seems that Andrew Carnegie was in England in 1910 and met Lord Cromer, who had returned from his important work in Egypt and had accepted the chairmanship of the Central African Research Committee, an organization formed for the development of the agricultural and other resources of central Africa. Cromer complained to Carnegie that they had no young men who were doing practical work in entomology and that such men were greatly needed. Whereupon Carnegie told him to arrange to send three young men from England every year, each for a period of three years, if he liked, to study in the American universities and in the Bureau of Entomology at Washington. This generous offer was promptly accepted, and the young Englishmen began to come over, continuing until the outbreak of the war.

During this period, also, Carnegie paid the expenses of a German professor and of a distinguished French entomologist on visits to the United States for the same purpose. After the war and at about the time when England was ready to begin sending over more young men, Carnegie died (August 11, 1919). He left no provision in his will for the continuance of this unusual fund. But it so happened that there was a balance left, and three or four additional students were sent over after the war.

This was one of the many unadvertised and at the same time admirable ways in which the great giver spent smaller sums as compared with his large benefactions, and surely it has accomplished much good. The men trained in this way have, most of them, gone out to colonial posts where their work is vastly more efficient than it would otherwise have been, and at the same time they have had the personal contact with American workers that has made them friends and helpers for the rest of their working careers. As a simple generalization, it may be well to say here that there is a spirit of international helpfulness among the scientific men engaged all over the world in this fight against insects—such a spirit, probably, as is equaled in few other human activities.

As to the other countries, Italy for years has been supporting two admirable stations—one at Portici near Naples and the other at Florence—and, since the war, has been extending this work very largely. Holland, both at home and in the Dutch East Indies especially, has been engaging the services of a number of experts. Sweden and Norway and, later, Spain and Portugal, have started governmentally endowed research. Japan has been doing the same for years. And as the world has grown normal after the terrible shock of 1914 to 1918 and the absolutely abnormal condtiions that resulted, interest in these questions has been increasing. The new nations have begun. The present Poland, Czechoslovakia, Jugoslavia, Rumania, the new Greece, and Palestine are encouraging research work looking toward control of insect pests.

I began nearly three years ago the preparation of a history of applied entomology.[2] Although when I began I thought that I had a fair knowledge not only of recent developments over the

[2] Published Nov. 29, 1930, as Vol. 84, Smithsonian Miscellaneous Collections.

world but also of the history of these developments for the past fifty years or more, I was surprised and pleased to learn many new facts and to come to realize much more markedly than before the rapidity of the growth of the work against injurious insects during, say, the last decade. I succeeded finally in confining my account to a volume of 550 pages, but in this I was obliged to include an account of work in no less than seventy countries. It is a comforting thought that in each of seventy countries there is a force of men working on the different aspects of the injurious-insect problem. It is true that in some countries there is only the smallest handful of men, but in others there are very many more —in the United States over a thousand. Almost everywhere this number is being added to year by year. In fact, it looks as though humanity were on the verge of awakening to the full menace of insect life.

As to the men who work with insects simply as a biological field of study and who do not concern themselves directly with matters of control, it is regrettable that their numbers are not increasing so rapidly as are those of the applied workers. On the whole, it is doubtful whether there are any more amateur students of insects to-day than there were fifty years ago; indeed, there are fewer in proportion to the population.

Nevertheless there are evidences that the interest of the truly scientific men in this subject has been growing. There has been published in London since 1864 an annual volume entitled "The Zoölogical Record," which prints the titles and analyzes the contents of all papers published annually on the subject of zoölogy. I have recently glanced through the last ten volumes of this useful work, and find that, while it has been growing in size from 690 pages in 1920 to 1,133 pages in 1929 (1,221 pages in 1928) and the number of publications considered have grown from 2,016 to 2,955 (3,230 in 1925), the parts relating to insects have grown correspondingly. The pages devoted to entomology in 1920 numbered 289, and in 1929 reached 436.

Probably the increase of interest in the United States is shown quite as well as in any other way in the rise of the Association of Economic Entomologists. This important association, started in 1889 by a small group of men, reached a membership of more than one thousand by 1929. Its publication, known as the "Journal of Economic Entomology," begun in 1907, has grown rapidly, and now each monthly number fills nearly three hundred pages. The articles are all brief, quite to the point, and carefully summarized.

But the mere citation of the number of workers and of the number of printed pages, however rapidly they may be increasing, does not give any indication as to the spirit of the workers or the quality of the work. It is doubtful whether there is in any branch of applied science a more interested and more enthusiastic body of students.

In Europe, for example, where the importance of insects from the economic point of view has been appreciated much more since the World War, many men have taken up the work who have not been trained for it. In France, at the close of the war, just as in other countries, the necessities for a highly productive agriculture were very great. The result was that the Government, financially weak as it was, devoted larger sums to all scientific work bearing on agriculture. Dr. Paul Marchal, the famous entomologist, was given funds for the establishment of a number of regional laboratories.

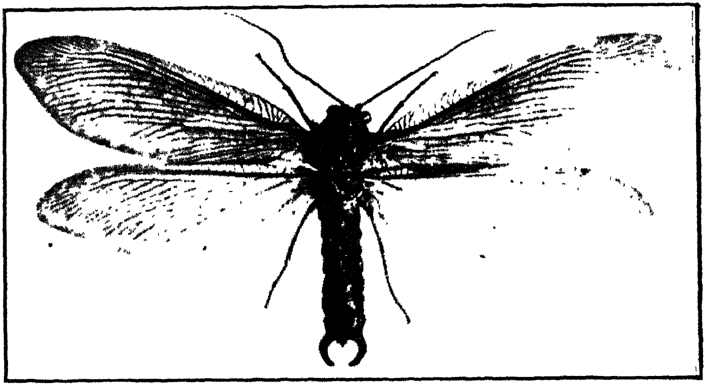
But where were the men to fill the posts? Eventually they were all filled and very competently, but I was especially interested in two cases. For the Rouen post Marchal found Robert Regnier, a young man, son of a wealthy family whose estate was in the invaded region, and who prior to the war had been studying oceanography. As a boy he had collected butterflies, but, shouldered into the work as he was, he found it fascinating. Everything that he had ever learned came into play. His biological knowledge and the technique gained in his oceanographic studies were found to be of the utmost assistance, and he has developed into an advanced worker.

The other case was that of Raymond Poutiers, who before the war as a very young man had been engaged in industrial chemistry. He too in his boyhood had collected butterflies and he was a member of the great Entomological Society of France. Dr. Marchal found him and put him in charge of an important station at Menton. Naturally his chemical training helped him, and he soon developed not only a keen perception of the biological necessities but a tremendous interest in the general subject. He found, as did Regnier, that everything that he had ever learned was of use. He is now engaged on an important branch of the work at Antibes.

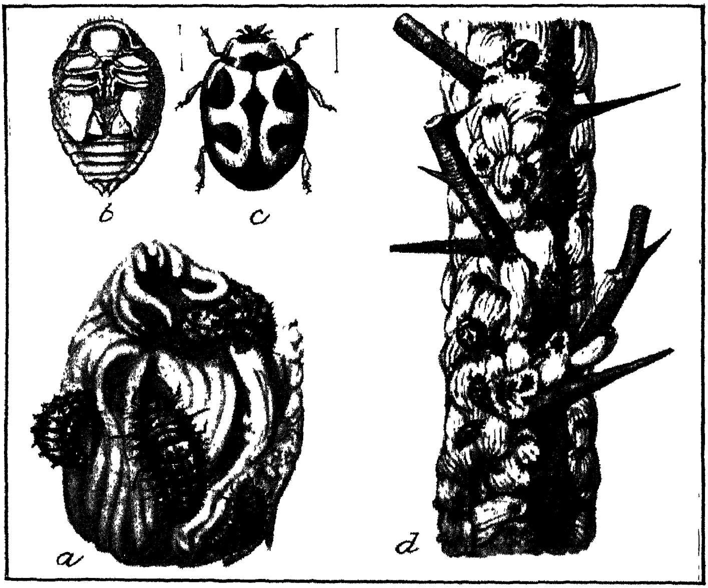
I have had no more inspiring experiences than to see these men forgather from all over the world at Ithaca, New York, in August, 1928, at the Fourth International Entomological Congress. While the other aspects of entomology—the purely scientific aspects—were considered in different sections, the group of economic entomologists was by far the largest and apparently the most enthusiastic.

Even the entomologists themselves, however, have only recently begun to realize what must be done before we shall have a comprehensive understanding of the best means of fighting insects. Almost down to the present time we have been obliged to devote our attention chiefly to what can be termed only surface measures, intended to meet the needs of the moment. Hand-picking, crushing by mechanical means, poisoning with internal poisons, and killing with contact insecticides, are the most obvious measures, and all can be done without knowing much more than the general life-history of the injurious species. With a knowledge of the life-history, we know at which stage and therefore at what time of the year the work can be carried on to the best advantage—that is, in such a way as to destroy the greatest number at the least expense.

But a fight like this is wasteful—it demands great outlays of money—and deeper studies will surely show more fundamental things. It is for this reason that we have begun to study the problem of natural control to which we will refer more in detail later; and our beginning includes the practical use of the insect parasites of injurious insects, although this is only one of the most obvious methods of natural control. Then too we have begun to study the intimate life-history of the insect in its exact relations to the present methods of growing our crops, in order to see what variations in cropping methods will fail to



The Australian "Moth Lace-wing"—*Ithone fusca.* Enlarged 2.2 times. (From Tillyard.)



The Australian ladybird (*Novius cardinalis*): *a*, larvæ feeding on fluted scale; *b*, pupa; *c*, adult; *d*, a branch covered by fluted scales upon which both adults and larvæ of the Novius are feeding. (U. S. Dept. Agriculture.)

give the injurious insects the same opportunities for increase and destructive work they now have.

But our studies must go even deeper, and we must bring about a thorough understanding of every feature of the great insect plagues. New ideas are being suggested constantly by a small army of bright and well-trained young men who are entering upon this field, and our knowledge is increasing daily. But it must increase more rapidly, and the small army of clever men must become a large army.

Now let us go more into detail as to what has been accomplished, what has been done, and what seem to be the possibilities.

All living nature is engaged in a series of gigantic battles. The human species has had to fight for its existence from the very beginning. It is the same with all other animal species. And it is the same with the plants, since besides struggling for existence with rival plants they must evolve multifarious methods of species preservation against their innumerable enemies belonging to the animal kingdom. The so-called "battle of the forest" is really a tremendous one. A rock pool of sea-water during low tide shows a miniature struggle for existence going on strenuously with the small forms of sea life.

So with the insects. Not only do many other kinds of animals destroy them, not only do they form the principal food of many fish, reptiles, birds, and even some mammals, but there are great groups of them that live wholly on other insects. A famous physicist once said to me, "It is a mighty good thing that the insects fight so much among themselves; otherwise they would overwhelm us." And then, insect species that destroy other insects are themselves destroyed by still other insects. To the close observer, almost every old tree trunk, almost every yard of old turf, is a sanguinary battle-field where the mortality among the little creatures is very great.

The best word picture I have seen of one of the innumerable mortal struggles that go on is given by Tillyard in his account of the Australian *Ithone fusca,* the so-called moth lacewing.[3] This harmless-looking insect is a destroyer of certain other insects. Its larva is a white grub, living underground where it feeds on and kills another kind of white grub that is the larva of one of the May-beetles. The larvæ of the Ithone occur in multitudes under the soil in some places, at sufficient depth to insure moisture, and the adults emerge rather uniformly just about sundown during the fortnight from the end of October to the middle of November. At this late afternoon hour the adults come out in

[3] Bulletin of Entomological Research, XIII (1922), 205–223.

swarms, settling upon the trunks of trees, remaining there overnight and mating. Tillyard's account of the swarming and of the reactions of the Ithone's enemies is so interesting that it must be quoted in full:

On a favourable night, when *Ithone* may be expected to swarm, the whole of the life of the bush seems to be getting ready for the event. We could see huge spiders spinning their tough webs everywhere, in feverish haste; while battalions of ants of various kinds, especially Bulldogs (*Myrmecia*), Mound ants (*Iridomyrmex detectus*) and Greenheads (*Ectatoma*), began to swarm up the trees and take up expectant attitudes, waiting to pounce upon their victims. Huge Lycosid spiders, commonly called "triantelopes," came out from their lairs, also ready to pounce; and even frogs took up suitable positions at the bases of the tree-trunks.

Immediately the swarm begins *Ithone* falls a victim to its enemies in hundreds. Approaching my first tree, I saw four male *Ithone* struggling wildly, each in the grip of from eight to ten savage Greenheads, which had already bitten off most of their wings. On the next tree a male *Ithone* was struggling in the grip of a large spider; on returning later, I found that all except part of its wings had been devoured. A little further on, some Bulldog ants had seized a couple of victims; while in various places they could be seen struggling in the broad spiders' webs stretched from bush to bush. It was often a race between myself and these numerous enemies, to see who could secure the *Ithone* first. I should estimate that less than half of the swarm survives the first *mauvais quart d'heure*. In the early morning, the Thickhead and other birds are abroad hunting down the remainder, so that by 8 A. M. little of the previous night's swarm is left.

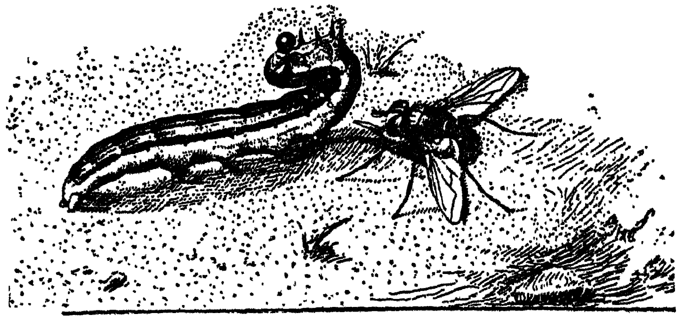
The actual flight of *Ithone* lasts under an hour, and it is necessary to search thoroughly for females while they are about, the males being so abundant that one could easily secure 50 or so without getting a single female. By the time darkness has set in the flight is finished, and from then onwards only occasional specimens are to be got, either resting on trees, running about on the ground, or sometimes coming to light.

The so-called white grubs of the May-beetles and their allies are so injurious to pastures and to graminaceous plants in general in different parts of the world that attempts have been made to establish this moth lace-wing in other countries than Australia. Dr. Tillyard has sent many hundreds of them to New Zealand, and some years ago he sent more than a thousand to the United States in the hope that they could be acclimatized here and prove to be an important enemy of the larvæ of the Japanese beetle, a serious introduced pest. The American importation failed; the eggs sent over, despite the utmost precaution, failed to hatch; and I believe that the attempts in New Zealand also failed. No doubt the experiment will be tried again.

There are families of beetles, comprising thousands of species, that live exclusively upon a diet of other insects. And there are great families of sucking bugs that do the same. Then there are immense groups of Hymenopterous insects (allied to the wasps and ants) that are all so-called parasites of injurious insects; that is, they lay their eggs in other insects. These eggs hatch, and the issuing larvæ devour the internal anatomy of the victim. Then too, there is one very large family of true flies (the Tachinidæ) that have similar habits and are also called parasites. And certain flies of other families live in the same way. In addition to these there are insects throughout the different orders that use other insects as a constant diet; some of them are parasites and others predators.

All through this complex there is the most extraordinary mix-up of results from cannibalism or parasitism. It is in one of the groups of Hymenopterous parasites that the phenomenon known as polyembryony occurs that results in the development of a thousand or two thousand or three thousand adults from a single egg. And in several of the families of this group it has been found that the egg of a parasite laid in the egg of an injurious insect does not hatch out, and the larva does not destroy the host egg; on the contrary, the egg of the injurious species hatches, and after the larva reaches a certain growth, *then* the egg of the parasite hatches and destroys its victim.

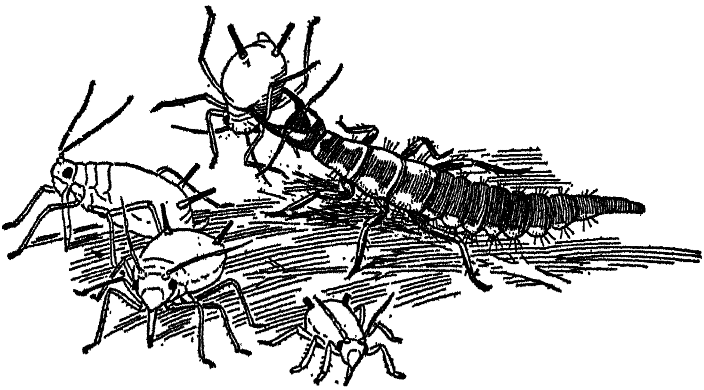
Among the Tachinid flies a curious difference has arisen. Some of them lay their eggs on the host insect, and, these eggs hatching, the larvæ penetrate to the interior of the caterpillar or



Army-worm attacked by a Tachina-fly. The white eggs will be seen on the back of the caterpillar, toward the front. The black globule has been emitted from the caterpillar's mouth, in fright. (After Walton.)

whatever insect is attacked, just as is the case with the Hymenopterous parasites. With other groups of these flies the eggs are not laid upon the insect to be attacked but upon the leaves on which it feeds, and the egg of the parasite thus enters the stomach and hatches into a larva that devours the internal organs. This is the case with a Japanese parasite of the domestic silkworm, and was discovered more than thirty years ago by Sasaki. And there is a third way in which these parasitic Tachinids achieve their end. They may lay their eggs upon the bark of trees and twigs likely to be crawled over by certain caterpillars—for example, caterpillars of the gipsy-moth. The eggs hatch in the warm sunshine, the little larvæ rise on end when they feel that a caterpillar is approaching, and as the caterpillar marches ahead over the insignificant creatures, the latter penetrate its belly and find themselves at home devouring the fatty tissues and later the vital organs of the victim.

The extraordinary variation in methods of life of these so-called parasitic forms in the flies bids fair to be equaled with some of the Hymenopterous parasites, judging from close observations the results of which are announced from time to time. For example, there is a little group



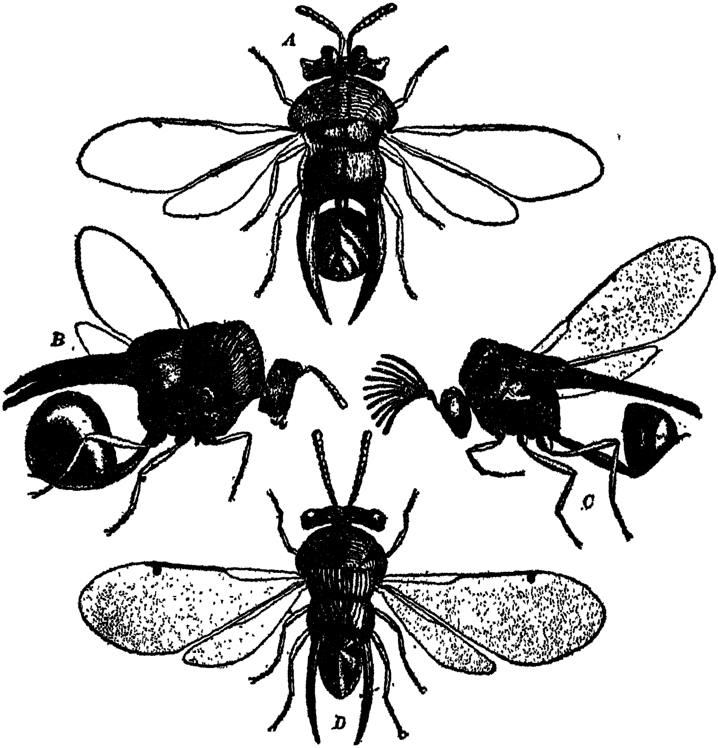
Aphis-lion (larva of a lace-winged fly of the family Hemerobiidæ. (From Snodgrass. Courtesy U. S. Dept. Agriculture.)

known as the Eucharidæ. For a long time their intimate habits were unknown. They were supposed to be parasites, but no one knew what kind of insects they attacked. Eventually the adults of one species were found in ants' nests, and a parasitism of ants was suspected and finally proved by Dr. W. M. Wheeler.

Dr. Wheeler found, to every one's surprise, that the young larva on hatching from the egg is a very active creature which crawls about rapidly and is structurally fitted to find its own host; resembling, in fact, the first larva of certain blister-beetles that attach themselves to the legs of bees and are carried to the nests where they enter the bee larvæ and undergo with each molt structural changes of such remarkable character that they have been called hypermetamorphoses.

Later much the same phenomenon was discovered by Harry S. Smith with the parasites of the genus Perilampus which belongs to a family structurally allied to the Eucharidæ. A much later chapter was written by C. P. Clausen. In Japan he discovered one of these Eucharids (*Schizaspidia tenuicornis*) which is parasitic in the mature larvæ and pupæ of a species of ant. The striking point is that he found that the parasites lay very numerous eggs in the large and loosely formed buds of a plant of the genus Flamingia, thrusting them into the interior of the bud. The active young larvæ, on hatching, attach themselves to the legs of prowling ants and are thus carried to the ants' nests. Later still, Clausen worked out in Japan the life-history of still another species in which the eggs are laid in ribbons that may contain as many as a thousand and are thrust under a bud scale. He showed that after the eggs hatch the larvæ may live twenty-four days without food, all the time waiting for the prowling ants to which they will attach themselves when the chance comes.

Thus in one way or another insects themselves are with little doubt the most important natural enemies of other insects, and many a threatening outbreak of an injurious species upon valuable crops has been suddenly stopped by their action. Hubbard, for example, found more than forty-five years ago that in a cotton-field in Alabama over 98 per cent of the eggs of the cotton-moth had been pierced by parasites. In 1879 I found in a tremendous field of timothy grass near Portsmouth, Virginia, a veritable multitude of army-worms that had invaded it, and although I searched for some hours I could not find a single caterpillar that did not bear upon its back the eggs of a species of Tachina-fly, and I was



Two Eucharid parasites of ants: *A* and *B, Isomeralia coronata; C* and *D,* male and female of *Kapala floridana.* Greatly enlarged. (After Wheeler.)

able to assure the owner that his field would be spared despite millions of caterpillars that threatened it.

In the same way, in 1881 at Huntsville, Alabama, the wheat-fields were being destroyed by immense numbers of this same Northern army-worm. I visited the spot and found one place where caterpillars had marched into a railroad cutting between two fields in such numbers that the ground was covered by them to a depth of several inches. The significant fact is that apparently from miles around parasitic and predatory insects had flown in. Wherever one looked he could see the Ichneumon-flies and Tachina-flies laying their eggs upon the struggling caterpillars, while Carabid beetles and large predatory bugs were destroying the army-worms by the thousands.

As recently as 1899 I discussed rather seriously the economic value of insects as a class, contrasting the damage done by them with the benefits that the human species has received from them. There is not the slightest doubt that in the intervening thirty-odd years the damage has increased enormously and that people generally look upon insects as almost unmitigated pests. We forget for the moment their value to us as destroyers of weeds, as pollenizers of plants, as scavengers, as makers of soil, as food for poultry and song-birds and food-fishes, as makers of clothing (silk), and as used in the arts, but especially as destroyers of injurious insects.

In the address mentioned above [4] I considered

[4] Address of Retiring President of the Biological Society of Washington. "Science," n. s., IX, No. 216, pp. 233–247, Feb. 17, 1899.

numerically 300 of the principal families of insects and concluded that of these families 116 were injurious to man, 113 were beneficial to man, and 71 contained either both beneficial and injurious species or species of undetermined economic status. It was rather a surprise to find that, of the 113 families comprising beneficial species, the insects of no less than 79 families prey upon other insects. A family is an immense group, in many cases comprising hundreds of genera and thousands of species; so that predatory and parasitic insects must be very abundant and must be an extremely important factor in the preservation of the so-called balance of nature. In fact, I am quite convinced that they are of far greater importance than the insectivorous birds and the other animals that destroy insects.

Taking these things into consideration, it is not strange that the economic entomologists during the later years have been making every effort to increase the efficiency of so-called beneficial insects, and, beginning with the introduction of the famous Australian ladybird beetle into California to destroy the fluted scale in the 1880's, work in this direction has been going on to a greater and greater extent in many countries down to the present time. It has now become a thoroughly accepted line of investigation in the case of any insect pest that has been introduced accidentally into one country from another.

In a number of instances such work has been dramatically successful, but very few have equaled in simplicity, completeness, and rapidity the case of the Australian ladybird. The introduction of this insect from Adelaide to the vicinity of Los Angeles resulted in saving the orange- and lemon-growing industry of southern California from rapidly approaching extinction by the fluted scale, and it accomplished the result in a few months. Similar benefits have since been gained by the use of the same little beetle against the same injurious scale in South Africa, Portugal, Italy, the South of France, New Zealand, Hawaii, and other places. This species of beetle (*Novius cardinalis*) seems to feed only upon scales of this particular kind.

One of the most striking instances of the sort was the work done under the auspices of the Hawaiian Sugar Planters' Association some years later than the California work. The extremely valuable sugar-cane industry of the Hawaiian Islands was rapidly being made unprofitable by a leaf-hopper that sucked the sap of the leaves and canes. Experts were sent to various Oriental and Australasian regions in search of parasites and natural enemies of the leaf-hopper. This time the search was longer and the introduction of the beneficial species finally found was much more difficult. In fact, the whole story is one of almost romantic interest. Years afterward it was told effectively by the Hon. James R. Mann, Chairman of the Appropriations Committee of the United States House of Representatives. In introducing an appropriation bill, he began with the words, "I have a fairy-story to tell you," and then went on with the relation of the trials of the experts and of their final success. It need only be said here that they found competent parasites of the leaf-hopper eggs and introduced them into the Hawaiian archipelago with the result that the sugar-cane industry was saved.

A branch of mulberry, in Italy, partly covered with the scale-insect *Diaspis lanatus*, some of which have been killed by the parasite *Prospaltella berlesei*. Some of them show the round exit holes of the parasite, and two of the little adult parasites are shown. Much enlarged. (Redrawn from Berlese.)

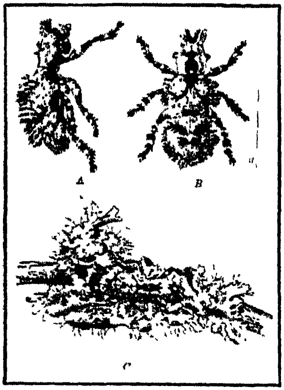
Another very successful importation developed fifteen or more years ago. There was a scale-insect of almost cosmopolitan distribution that in Italy seemed to be especially injurious to the mulberry tree, and of course upon the mulberry depends the silk industry of Italy. So seriously did the insect affect the vitality of the trees, and so difficult was its control by insecticidal washes of any kind, that Professor Antonio Berlese introduced, with the help of the people in Washington, D. C., a minute parasite of this and allied scales. After a time the little parasite multiplied so successfully as virtually to control the scale-insect over a large part of Italy and to relieve the silk-growers from the threatened disaster.

There have been a number of other cases of marked benefit derived from the proper transfer of parasites from one country to another, but there have also been many failures. Some of the failures have undoubtedly been due to insufficient knowledge of the biology of the parasite; others have been due to improper methods of collecting and packing for shipment; still others have been due to improper handling after receipt. From all such experiences, however, we have learned, and these international attempts are going forward now with better hope of success in many cases. Of course there will be many failures in the future; some parasites will fail to become established under new surroundings.

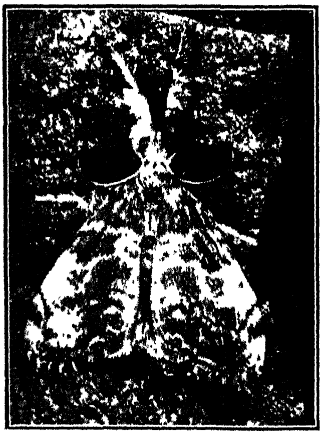
But in general it is safe to suppose that the specific parasites of a species will live and thrive wherever the host insect lives and thrives.

Before we leave the subject of international handling of insect parasites, it will be interesting to tell something of the latest and apparently one of the most successful and striking experiments. In the Fiji Islands copra is, next to sugar, the most important export, and since 1877 the foliage of the cocoa-palms has been eaten by the larva of a little moth which has come to be known as the Levuana caterpillar (*Levuana* being the Latin generic name of the species). The damage had been increasing until by 1924 the industry was threatened with absolute ruin. The green palms all over the island had become a dingy gray. Attempts to retard the increase and spread of the insect had utterly failed.

In 1924, at the Wembly Exposition in London, Sir J. M. Hedstrom of Fiji consulted with the home authorities, and on the advice of Dr. (now Sir) G. A. K. Marshall, it was decided to undertake a thorough and if necessary long-time entomological investigation. Mr. J. D. Tothill, who had had much experience in biological control investigations in Canada and the United States, was appointed director of the campaign, with Messrs. T. H. C. Taylor and R. W. Paine as assistants. The undertaking was financed by a



A Madagascar beetle—*Lithinus nigrocristatus*—*A*, from side; *B*, from above; *C*, sitting on a lichen, *Parmelia crinita*, from which it can hardly be distinguished. (After Schroeder.)



Male white-marked tussock-moth. An example of protective resemblance. (After Quaintance & Siegler, U. S. Dept. Agriculture.)

A sphinx moth—*Ceratomia amyntor*—at rest on the trunk of a small tree. A striking instance of protective coloration. (Photograph from U. S. Dept. Agriculture.)

tax of two shillings and sixpence per ton of copra and an equal contribution from the general revenues, making an annual budget of five thousand pounds.

It soon developed that a curious situation existed. The insect could be found only in Fiji, and yet no native parasite existed there. Explorations by H. A. Simonds (then Acting Entomologist) in 1923, covering the New Hebrides, the Bismarck Archipelago, Solomon Islands, Lord Howe Island, Norfolk Island, and northwest New Guinea, did not result in discovery of the pest or of any allied species. It was therefore necessary to look elsewhere, and for any possible allied insects that were parasitized. Mr. A. M. Lea, Government Entomologist of South Australia, was sent to Malaya and Java, and eventually secured and imported several parasites from Java of a genus, Artona, allied to Levuana.

To cut a long story short, one of these parasites sent in from the Federated Malay States by Mr. B. A. Gater was a Tachinid fly described by Dr. J. M. Aldrich of the United States National Museum as *Ptychomyia remota,* and this fly has proved to be the salvation of the islands. Although apparently normally a parasite of the Artona, it readily attacked the Levuana caterpillar, and at the present time controls the pest perfectly.

There can be no doubt that the long series of parasites introduced by the United States Department of Agriculture from parts of Europe and from Japan to aid in the fight against the gipsy-moth and the brown-tail moth have done remarkably good work. While they have not absolutely controlled these species, they have undoubtedly greatly reduced their numbers. In the same way the Department of Agriculture has been introducing parasites of the Japanese beetle, European corn-borer, the alfalfa weevil, the European earwig, and other accidentally introduced injurious insects. In many cases a very long time may elapse before good results from such introductions are obtained. We have known instances in which an introduced species of parasite apparently disappeared and it was thought that it had not succeeded in becoming established, and then after a lapse of twenty years it has turned up in force.

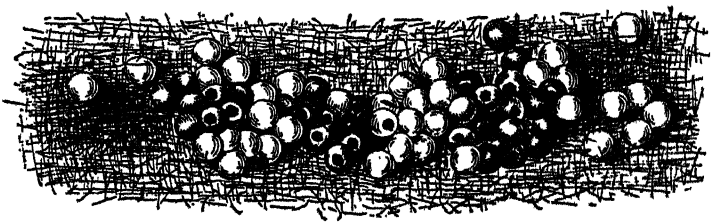
But these international introductions comprehend by no means all that we want to do with parasitic and predatory insects. If we could only handle them like domestic animals—if we could breed them successfully in confinement and liberate them when needed, and do this with our native parasites against our native pests! This is not an idle dream; some work of the sort has already been done. As it happens, there is a very minute Hymenopterous insect, known as *Trichogramma minutum,* that lays its eggs in the eggs of numerous other kinds of insects; and its larvæ destroy the eggs of the host.

The genus *Trichogramma* was established about a hundred years ago by the famous English entomologist J. O. Westwood. The original specimen was found on an oak leaf in Epping Forest and had probably issued from the egg of some little moth. No one knew anything about its habits, however, for many years. Then Trichogramma began to be reared from the eggs of many different kinds of insects, both in Europe and in the United States, as well as elsewhere in the world. A subfamily and then a family were erected, and numerous genera and species were described. Virtually all of the European forms, however, as the Danish writer Kryger has recently determined,

A female Trichogramma laying her egg in the egg of a moth. (After Howard and Fiske. U. S. Dept. Agriculture.)

belong to the same species, and all are probably identical with the little creature that Westwood described; and it is altogether likely that the American species are also identical with the European.

Many insects hibernate in the egg stage, and these eggs are laid on the bark of plants, and plants in great numbers are carried from one country to another, so that, as is well known, not only are injurious insects introduced accidentally into strange countries but many of them carry their parasites with them, and it is no longer possible to speak definitely of the indigenous geographic distribution of very many forms. The little Trichogramma seems to lay its eggs in almost any insect egg the shell of which it can penetrate with its ovipositor. Of course the shells of some are too hard, but those of many others, very many, belonging to various groups, can be penetrated, and the Trichogramma lays its eggs in these, apparently only one or two in a small egg



Eggs of brown-tail moth, many of which have been parasitized by Trichogramma. (Howard and Fiske.)

Packages of parasite material, received from Europe, at the Gipsy Moth Laboratory at Melrose Highlands, Mass., about 1909. (U. S. Dept. Agriculture.)

Liberating parasitic Tachina-flies, reared from imported stock, against the gipsy-moth near Melrose Highlands, Mass. (U. S. Dept. Agriculture.)

and as many as fifteen to thirty in a larger one; and the number of eggs of injurious species that are thus destroyed is beyond computation.

This parasite, then, seems to offer especial advantages for what may be termed industrial or commercial exploitation. As long ago as 1903 it was known in Astrakan, and in 1913 two Russian authors, A. F. Radetezky and N. N. Troitsky, began to work with it. Their efforts attracted the especial attention of writers in other parts of Russia, namely J. F. Schreiner and W. Pospelov. The great Russian entomologist Porchinsky had already shown that by the use of different host insects a supply of these parasites may be maintained. But the war came on, and we do not know what further progress was made. Probably the investigation was abandoned.

In the United States we have during the past sixty years reared Trichogramma from the eggs of many insects, but it was not until quite recently that Mr. S. E. Flanders conceived the idea of rearing them commercially. He was at that time the entomologist of a walnut-growers' association at Saticoy, California; and the well-known codling-moth of the apple had begun to attack walnuts. He knew that the eggs of the codling-moth are parasitized by Trichogramma, but he knew also that it would be difficult to secure a supply of living material from this source. He thought a bit, and hit upon one of the little moths that breed abundantly in stored grain. This insect could be bred with the utmost ease in confinement and on an enormously large scale in comparatively small quarters, and its eggs, he found, were freely parasitized by Trichogramma. He therefore, exercising great ingenuity, was able to rear literally millions of Trichogrammas and to distribute them in large numbers among the walnut-growers, to be liberated in their orchards.[5]

In the meantime experimental work has been going on with this particular parasite in many parts of the world—in Berlin, in Paris, at several points in the United States, and elsewhere. The whole idea seems to be promising. By a curious coincidence, as I was dictating these lines, my afternoon mail came in, and the first envelop I opened contained a circular with the heading: "Announcement of Trichogramma parasite prices for 1931," and the price-list shows a range varying from fifty cents for one thousand parasites to two thousand dollars for ten million parasites. They are said to be put in units of approximately two hundred parasitized meal-moth eggs, ready for distribution in orchards or elsewhere, the material to be placed in cold

[5] The same parasite has been reared by millions in Louisiana and released in the sugar-cane fields to destroy the eggs of the moth borer. Good results are reported.

storage at temperatures between 32° and 38° Fahrenheit until conditions warrant distribution and the issuing of the adult parasites.

This is commercialism with a vengeance, but it is commercialism based upon sound experimental work in an entirely new field.[6]

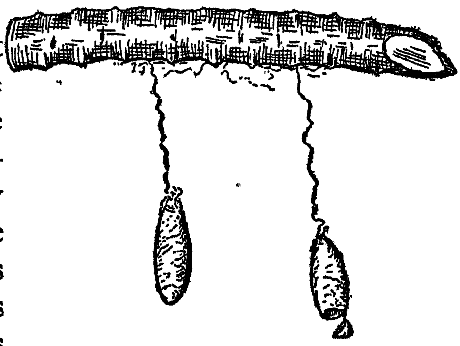
Entomologists all over the world have been studying these insect parasites for some years and very many of the parasites are known, and many facts about them are known, and many scientific papers referring to them have been published. At an earlier date such was not the case. A few entomologists were sent out from this and other countries to look for parasites. Following the original expedition to Australia by an assistant in the Federal Bureau of Entomology, named Albert Koebele, other men went to Australia and Oriental countries from the United States; men were sent from Hawaii to many parts of the world; South Africa sent two men over to South America; Italy sent Professor Filippo Silvestri down into Africa, and the same

[6] There had been going on in California for some years prior to this work of Mr. Flanders with Trichogramma, actual commercial rearing of a little Australian beetle known as *Cryptolæmus montrouzieri* that feeds upon mealybugs. The Citrus orchards in that part of the country suffer severely from mealybug attack, and the beetles have been reared upon a very large scale and sold to the proprietors of large Citrus orchards, and their work has been admirable. It has been found that the cost of biological control in this way is very small compared with the cost of spraying or fumigation. Moreover, spraying and fumigation are by no means as effective against mealybugs as they are against other scale-insects.

able investigator was afterward employed to travel for the Hawaiian Government and for the State of California. The Federal Bureau of Entomology has sent men to Central and South America, to the West Indies, to all parts of Europe, to China and Japan and India, in search of parasites of crop pests that had been accidentally imported and established in the United States. There is a very picturesque and almost dramatic side to this work, although it involves frequently many hardships, and necessitates imagination, fertility of resource, persistency, and boundless energy on the part of the investigators.

The reactions of the people inhabiting the countries to which these men go are sometimes naïve and interesting. Dr. Marlatt in the early part of the century went to China. He was investigating the question of the geographic origin of the San José scale, and in his minute examination of the scales that he found on the small native haw-apples he attracted the attention of the country people, whose satisfactory explanation of his occupation was that he was hunting for medicine. Again, in the South of France, one of the agents was collecting large numbers of gipsy-moth caterpillars in order to rear the native parasites—or in order to send them to Massachusetts where they would be reared—and created much excitement among the peasants, who could not imagine for a long time why they were being paid for collecting these caterpillars en masse. A very old peasant, however, finally gave what he considered to be the real explanation, and it was accepted. "It is well known," he said, "that every millionth caterpillar has a diamond in its head, and this is undoubtedly why this man is having them collected in such great numbers."

I once told a story to the American Association of Economic Entomologists that illustrates the qualities of the resource, persistency, and energy needed by the traveling agents engaged in this work perhaps better than any general statement could. Here is the story:



Cocoons of *Limnerium disparidis* while still hanging to a twig. (Original.)

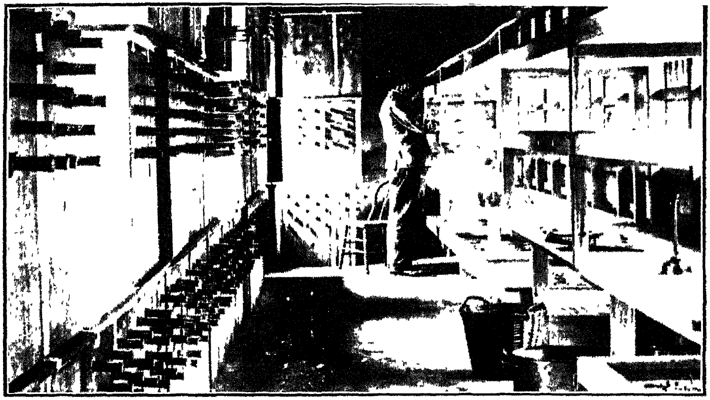
A parasite of the gipsy-moth had been received from Russia. We knew it only by the fact that its cocoon hangs suspended from the twig or leaf of a tree by a long silken thread. This parasite was called *Limnerium disparidis*. It was a rare parasite in the sendings that were made to the United States from Russia, and W. F. Fiske of the United States service, a man skilled in such matters, thought that the reason more were not found was that the thread breaks sooner or later and that the cocoon drops to the ground.

On June 15, 1911, Fiske found himself in the middle of a forest at Gioia Tauro, Sicily, where he was studying the results of parasitism following a destructive outbreak of the gipsy-moth, and, examining the remains of the caterpillars in an effort to tell just which parasite had killed them, his attention was continually attracted to larvæ hanging by their hind legs much as do those attacked by the wilt disease, with their bodies containing a few drops of blackish fluid. It was not wilt, he was certain from the first, and by tracing the various stages of decomposition backward he was able to associate it with parasitism by Tachinids.

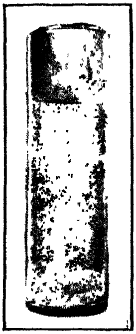
Mingled with these dead larvæ were a number of others pellucid in appearance, looking much like brown-tail caterpillars killed by certain species of Apanteles. Fiske puzzled over the phenomenon for a moment, until, with a burst of incredulous enlightment, he hit upon the solution. Holding his forceps exactly beneath such a larva, he let them drop to the ground, and at the spot where they struck, fully exposed, was a fine fresh cocoon of the long sought for and constantly despaired of Russian Limnerium, which, as above stated, was not known to exist outside of Russia. The experiment was repeated again and again with other caterpillars and in every instance with satisfactory results. In the afternoon of the same day, in another forest, he found the parasite much more abundant. In seven minutes he collected fifty on a bit of hard-trodden path where all that fell were exposed, and a little bit to one side, beneath an especially large and leafy tree, he collected twenty-five from approximately one square yard of surface.

In the evening he talked the matter over with his native assistant and interpreter. He asked him to make a formal call on the mayor of the village; to present his compliments and tell him that Mr. Fiske would be pleased to call on him in person, but that he was not expert in the Italian language; that he desired to send the children of the commune into the public forest for the purpose of collecting a quantity of insects which abounded there and for which he had a particular use, and that he wanted to find some responsible person recommended by the mayor who could be prevailed upon to receive these cocoons and pay for them at the rate of one *centesimo* each and forward them to Fiske at Portici. The assistant objected. He said it was not good form to call on the mayor in this unceremonious way and he refused to do it; so they finally compromised on the assessor. Again there were objections, but presently the assistant went, and came back with a queer look on his face. He had visited the assessor, it appeared, but the latter was very much inclined to think that he had either an idiot or a madman to deal with. He said he would interview the forest guards and see if there was likely to be anything out of the way in allowing them to take advantage of such an offer.

The next morning about six o'clock two forest guards, two children, and a number of dogs proceeded with Fiske to the forest, where he gave a demonstration of what he wanted. At first it was a flat failure. The guards could not find any cocoons themselves, nor could the boys, but by working hard himself and showing the boys where the cocoons lay he succeeded in getting them to pick up ten each, and rewarded them each with a couple of *soldi*. This livened things up a bit. The guards still could not find the cocoons, but the boys were beginning to see light, and before long they were collecting them in some numbers and kept Fiske fairly busy counting them and paying over *soldi*. The guards watched the transfer in growing amazement and enthusiasm, and at the end of an hour they all went back to town, the boys with about three *lire*



Interior of a laboratory devoted to the rearing of imported parasites of the gipsy-moth, Melrose Highlands, Mass. (U. S. Dept. Agriculture.)



A colony of Japanese egg-parasites of the gipsy-moth ready to be taken into the woods and liberated. (U. S. Dept. Agriculture.)

Scene in Japan: Collectors of parasites of the Japanese beetle, employed by the United States.

Boxes of parasites of the Japanese beetle just arrived from Japan.

between them and Fiske with three hundred parasite cocoons.

The guards stated to the assessor that the operation was of no possible danger to the forest, one of them insisting that the Limnerium was a species of fruit, that it grew on the foliage, and that they themselves would gladly undertake the collection of the cocoons, or rather the payment for them, for the ten-per-cent commission offered. But there was a fiesta on, and the chance of getting anything further done that day was out of the question. Fiske wanted the boys to go back and take some more boys with them, but they deserted him before they got half-way. The combination of a *lira* apiece and a fiesta on the selfsame day was one which might never come again in a lifetime and they meant to make the most of it.

The next morning at seven the forest guards returned and Fiske explained the full details of the scheme, offered to advance three hundred *lire* (about sixty dollars) and thereafter pay for every shipment as they were received at Portici. He set the limit of expenditure at fifteen hundred *lire* and the time at two weeks. The offer was accepted, and he hurried to Messina and cashed a check, returning the same night to sign the agreement. During the day the guards had succeeded in getting eleven boys who had brought in 2,290 cocoons, which were paid for on the spot. The next day the promise was that thirty boys should be sent out.

Fiske then returned to Naples, and the cocoons began to come from Gioia Tauro. Naples at this time was virtually quarantined on account of the cholera. On July 6 a large lot of cocoons had accumulated, and a boat of the Lloyd Sabaudo Company was to sail that day for New York. The company officials said that they would not take the parasites. Fiske called on the United States consul, who told him he would do well to see the medical officer and get a certificate from him to the effect that he was willing to pass the packages and that there would be no trouble on their account in New York. The medical officer was out at luncheon, so Fiske got the packages from cold storage, where they had been placed on receipt from Gioia Tauro, and then to the consul's, but there was no medical officer and he was told that it would be impossible to see him that afternoon because he was attending a conference. But the consul wrote out a formal letter on fine stationery, and armed with this Fiske went back to the steamship authorities. They were impressed by the seal and the embossed heading, and while they were considering it the captain of the vessel came in and absolutely refused to allow the parasites to be put in his refrigerator. He said that if Fiske would let them go in the hold of the vessel he might consider it, but they could not be kept in the refrigerator.

Undaunted, Fiske started for the American Express Company office, calling en route at the International Sleeping Car Company's office, where he found that if he could start the sending on the 6:50 train that evening it might possibly go through by express without missing any of the series of close connections, in time to be shipped on the French Line boat *La Lorraine* from Havre the following Saturday at 7 P. M., arriving in New York on July 15 or the day after it would have to leave Naples on the next possible boat that sailed.

But he had almost no money and it was four o'clock in the afternoon. Nevertheless, he went to the American Express Company offices and proposed that some one should undertake to see it through, charges to be collected from the State of Massachusetts or from the United States Government. The traffic manager admitted that he would like the trip, and said that he was well acquainted with the French language and the idiosyncrasies of the French customs officials. The only difficulty was to get the parasites into some shape so that they would look like baggage, whereupon the head of the shipping department led the way to the rear of the offices and pointed out a pile of old trunks that had been blockading the passage for a long time. They were a motley lot, but when they were sorted over five were found that Fiske thought would do. The bundles of parasites were unpacked and repacked in these five trunks, and, the superintendent of the office having approved, the traffic manager started with his five trunks and an additional hamper on the 6:50 train for Paris.

The rest of the story is that the traffic manager made the journey without accident and got the trunks aboard *La Lorraine,* where they were put into the refrigerating room. They arrived in New York on time, were met by the Government Despatch Agent, hurried through the customs, and shipped to the laboratory at Melrose Highlands, where they arrived in admirable condition. When they were unpacked, virtually all of them were sound.

There are very few men aside from Fiske who would have accomplished this result. One of those few men, however, could very well have been Frederick Muir, who worked for a number of years for the Sugar Planters' Association of Hawaii and who accomplished some remarkable things. I think that the story of Muir's effort to find and to introduce into Hawaii an effective parasite of the sugar-cane borer is the best one of its kind of which I have any knowledge. The resourcefulness, the persistence, the heroic and long-continued effort (crowned as it was at last with triumphant success), were so great that the story must be told here, even though briefly.

The great enemies to the sugar-cane in Hawaii were the leaf-hopper and the cane-borer. Egg-parasites of the leaf-hopper were found. The cane-borer remained a serious problem. Frederick Muir, a son-in-law of the famous English entomologist Dr. David Sharp of the University of Cambridge and himself a well-trained entomologist, began in 1906 to consider the question of leaf-hopper parasites and possible cane-borer parasites. But we will tell simply the story of the cane-borer work.

Muir studied hard to find the distribution of the beetle borer. He discovered that it existed in most of the Pacific islands to New Guinea and Tenimber, the latter being the most westerly point where it had been found. He consulted the experts, the European museums, and the museum at Buitenzorg in Java. He started from Honolulu for the Orient in July, 1906.

The first six months were spent in southern China. The beetle borer was not found. Then several months were spent in the Federated Malay States and Java. Still the borer was not found. In Java he discovered related weevils in banana trees and in palms, but he could find no direct parasites. Then he went to New Guinea. The borer was known to exist in British New Guinea, where it was supposed to have been introduced; it was known that allied weevils were numerous there, and it was thought likely that some of their parasites had transferred their attention to the cane-borer. But this was not so.

Muir then went to West Borneo and spent some time there, and after consulting the Sarawak Museum he decided that the beetle did not occur in Borneo. He returned to Java and sailed for the Moluccas. Many weeks were spent there in search, and finally in November and December he discovered the borer in great numbers in the sugar-cane and in two varieties of palms. At that time of the year the sugar-cane had been cut, but some stalks remained in the ground and showed the beetle's work. In one variety of palm, known as the pinang palm, he found that the beetle bores in the soft center of the tree; indeed, he came across one old palm that was infested from the root to the crown, some forty feet, and contained many thousands of empty cocoons. No traces of parasites were discovered.

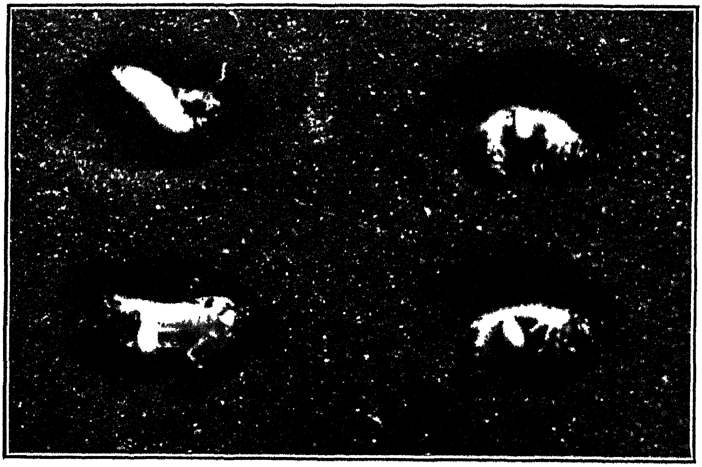
But he had learned a new fact, and that is that the sugar-cane beetle borer attacks palms in certain places. He went to Amboina and found the borer in sago-palms, and there he learned that it was attacked by a Tachinid parasite!

Now the problem was to get the parasite from Amboina to Honolulu alive. There was then no line of steamships through the Moluccas to Australia, and Muir thought of trying a sending from Amboina to Macassar, thence to Hongkong and then to Honolulu via Japan. But an experiment showed that the fly would die if it were transported in cold storage. Another man, Mr. F. W. Terry, was sent from Honolulu to Hongkong to receive the flies sent from Amboina and to try to breed them there. But this was a failure, since the connecting boat at Macassar did not call regularly and some shipments were delayed over a month on the voyage. Then Muir started, himself, to take a lot of the flies to Hongkong, and he managed to keep many of them alive until twenty-four hours from his destination, where they all died from no perceptible cause.

It now became necessary to return to the Moluccas and to try some other way. So in November Muir left Hongkong, accompanied by Mr. C. J. Kershaw. In the meantime he had received a specimen of the borer from southwest New Guinea, and he went there and to Fort Moresby, Papua, where both beetle and parasite were found. It was decided to stock some cages with beetle larvæ, expose them to the attacks of the parasites, transfer them to cages, and convey them to Honolulu via Australia. The first part of the program was carried out, but before leaving Fort Moresby, Muir came down with a fever, and on arriving in Brisbane had to go into the hospital with typhoid. His cages went forward, but there was nobody to attend to them and the specimens all died before they reached Honolulu.

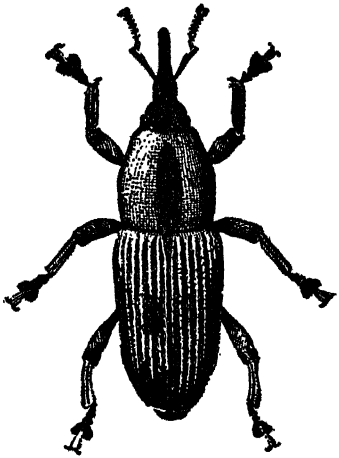
When he recovered from his fever, Muir returned to Honolulu to spend some time in the mountains, regaining his strength. It was then decided to establish breeding stations in Australia and also in Fiji, in order to relay the insects from Papua to Honolulu. In January, 1910, the indefatigable Muir left Honolulu, this time for Brisbane, where he had a struggle with the quarantine officials to get them to allow him to import his parasite material from Papua. But he succeeded, and, establishing a station at Mossman, Queensland, he went on to Papua.

Living parasites were taken by him to Fiji. He left on the point of coming down with malarial fever, and after his arrival in Fiji he was obliged to go into a hospital, but not before he had placed his flies in an outdoor breeding cage. He recovered, and on August 10 arrived in Honolulu with the material bred in Fiji. Many



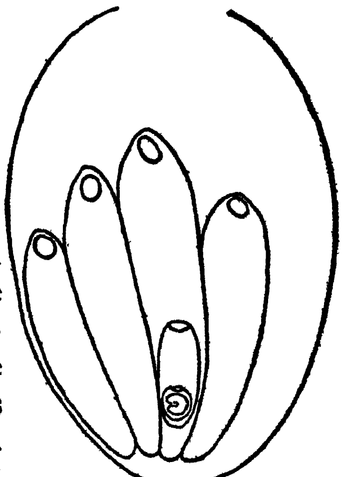
Larvæ of parasites imported from Japan feeding on the grubs of the Japanese beetle. (U. S. Department Agriculture.)

Wheat plot in center protected from Hessian fly by proper date of sowing. Early sown plots on either side completely killed. (Photograph by W. H. Larrimer.)



The beetle borer of the sugar-cane—*Rhabdocnemis obscura.* (After Muir and Swezey.)

flies hatched out, cages were stocked, Mr. Kershaw arrived in Honolulu a month later with other material, and the main object was accomplished. The breeding of the parasites in cages went on in Honolulu and the parasites were established in all plantations affected by the beetle borer. And this work was successful. The work of Muir and his assistants during four years brought about results of tremendous financial value to the Hawaiian sugar-planters, and it is pleasing to note that at present Muir is



A curious mix-up. The outer line is that of a pierced cocoon of the tussock-moth. The four outlines within are the pierced cocoons of an Ichneumonid parasite. Near the base of one of these cocoons is an outline of the puparium of some fly. Within this is the cocoon of a lace-winged fly; and within this is the larva of a parasite of the lace-wing.

residing, although in bad health, in the south of England, and that he receives a substantial pension from the Hawaiian people.

Much more could be said about this international work, and the searchers for parasites have had many unusual experiences that may some day be told in print. They are as interesting as the adventures of the explorers sent out by the Department of Agriculture for new plants, and I am sure that a book about them, if it could be written as well as David Fairchild's "Exploring for Plants," would be quite as delightful reading since it would be based upon even more interesting investigations.

To go back to the general subject:

There is a most astonishing mix-up in the relations of these parasites and carnivorous insects. Insects that parasitize other parasitic forms are known as secondary parasites. Insects that parasitize secondary parasites are known as tertiary parasites; and in this way even quaternary parasites have been found.

About thirty-five years ago I became exceedingly interested in such matters and worked out a probable quaternary parasitism among the insects that destroy the common tussock-moth caterpillars of the shade-trees in our national capital. It was during this investigation that I met with the following remarkable case. In December I was opening some cocoons of the tussock-moth and found one that contained several old and empty cocoons of *Pimpla inquisitor,* a Hymenopterous insect that is a primary parasite on the tussock-moth caterpillars. In one of the cocoons of the Pimpla, back at its far extremity, was the puparium of a scavenger fly of the family Sarcophagidæ from which the adult had issued. More in a spirit of idle curiosity than in the expectation of any result, I cut open this empty puparium, and here was another object, the cocoon of one of the lace-winged flies (a group of insects whose larvæ feed on plant-lice and other soft-bodied insects). This cocoon was intact, and upon cutting it open I found it to contain an adult of another species of Hymenopterous parasite belonging to the genus Hemiteles, all of the species of which are secondary, that is, parasitic within other parasitic larvæ. Therefore its larvæ must have destroyed some primary parasite of the lace-winged fly larva.

So, you see, the original tussock-moth cocoon contained (1) Cocoons of a primary Hymenopterous parasite; (2) a puparium of the fly whose larva had reached full growth after feeding upon the remains of the Pimpla pupal skins or perhaps dead pupæ as well, and had transformed within the Pimpla cocoon and issued; (3) a full-grown lace-winged fly larva which had crawled first into the tussock-moth cocoon, secondly into the Pimpla cocoon, and thirdly into the empty puparium, and with its little remaining strength had spun its own cocoon, only to die immediately thereafter from the attacks of a primary parasite already containing eggs of the hyperparasitic species of which I found the pupa.

While this example is not necessarily indicative of extreme parasitism, it is most interesting as showing how complicated life may be among these creatures, and how two cases of double parasitism may occur in a single tussock-moth cocoon.

Chapter VIII

THE WORLD IS WAKING UP (CONTINUED)

IN THE section dealing with the way civilization is helping the insects to increase and spread, it has been made obvious, I think, that the methods of agriculture have been responsible for most of the very bad conditions that confront us. This has all come about quite naturally. So long as there were new lands in abundance, as in North America and Australia, people burst out of the crowded older countries, occupied the fertile soil hitherto untilled in the new continents, and considered only the exploitation of the riches they found awaiting them. They did not look to the future. They got everything they could out of the land in the quickest way, and although the quickest way answered for a time it has proved in the long run to be the wrong way for present conditions and for future conditions. The methods used have, as we have repeatedly pointed out, resulted in the enormous increase of crop pests.

It has always seemed to me that the first studies of an insect outbreak should concern themselves with the history of the particular insect throughout its full life-cycle, and then to see how this history coincides with the culture and cropping of the particular agricultural product affected. In divers instances when the life-history of the insect is known it will be found that only a slight variation in crop practice will obviate most of the damage.

A few people have recognized this fact in the past. The English writer John Curtis as long ago as 1860 pointed out the value of comparative studies of the sort suggested here. And the old French writer Boisduval said once that entomologists had been criticized for studying insects and not working out the best means of fighting them, but that he felt that when the entomologist had worked out the life-history of a crop pest it was for the practical man, the farmer, to see how he could alter his farm practice to upset the chain of events in the insect's life.

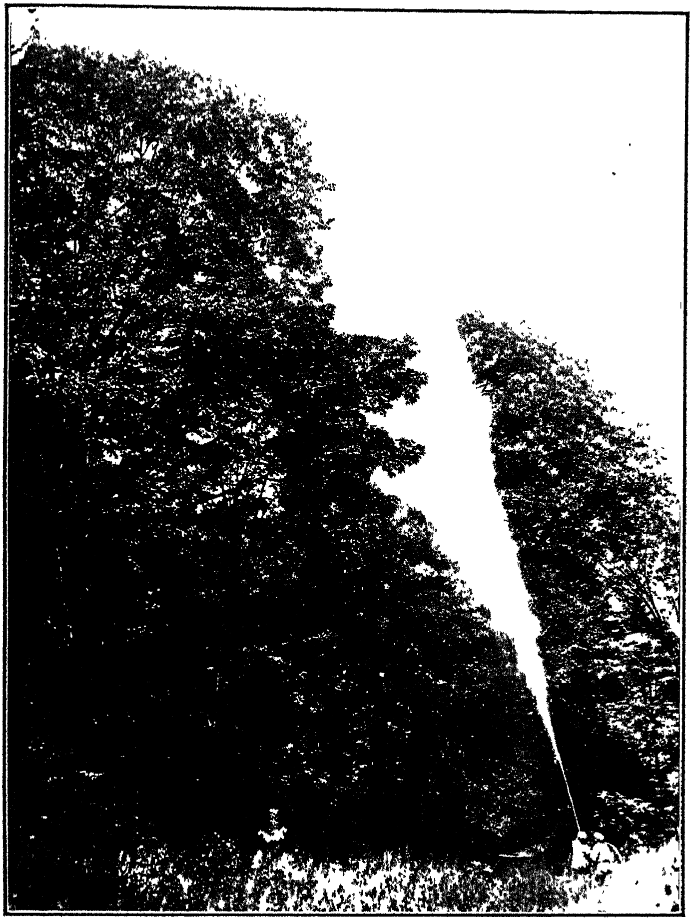
In the section referred to above we have pointed out briefly the satisfactory results obtained or to be obtained in the fight against the cotton boll-weevil, the European corn-borer, the clover-seed midge, and a few other pests, by alterations in farm methods. In nearly all of these cases, however, suggestions have met with slight response. Is it perhaps up to the agronomist, the man who plans farm operations, to work out a scheme whereby approximately equal profits could be gained by such variations as would fail to encourage the multiplication of insects?

I remember a meeting of the American Association of Agricultural Engineers held at Lake Tahoe in California a few years ago. I attended this meeting and saw on the program the statement that the entomologists had given up the European corn-borer work in despair and that the agricultural engineers must help out the farmers. As a matter of fact, what could the agricultural engineers do without the information that had been gained for them by the entomologists? We had worked out the life-history and had shown that for seven months in the year the insect lies helpless near the base of the corn-stalk. We had simply said to the engineers, in effect: "There you are! The problem now is for you to invent the best economical machinery for cutting down corn-stalks close to the soil."

We had also said to the agronomists: "There you are! We have shown you how and why this insect does such damage. We have shown that it can be controlled easily under a different cropping practice. Go to it. Teach the farmer how to arrange these crops and how and when to harvest them." And we say to the States if necessary: "Oblige the farmers by law to do these things. Negligent individuals are a danger to the rest. Pass legislation obliging them to cut their corn-stalks," etc.

It is perfectly obvious that in most cases insect-control by the methods of cropping and cultivation will depend for success upon the adoption of these methods by all the growers of a given region. Without such unanimity, the careless man or the non-believer will, by his retention of old methods, breed enough insects to infest a large territory. This is where legislation comes in and where it will be needed for a long time to come. Thus in Ontario there is a law—which is enforced—requiring the winter destruction of the corn-stalks to control the corn-borer. It may seem strange that a good law is often not enforced. During a strenuous clean-up campaign against this insect in 1927, the States of Ohio, Indiana, Michigan, Pennsylvania, and New York passed laws similar to that of Ontario, but three of these States attempted no enforcement after that year, while Ohio tried enforcement in only one county in 1928, and Michigan did the same that year in her worst infested district.

Illinois has a law directing the early planting of wheat as a means of eliminating damage by



Throwing a poisonous spray in a New England forest. (U. S. Dept. Agriculture.)

the Hessian fly. But the law is never enforced, largely for the reason that the wheat-growers generally adopt so-called "fly-free dates" for wheat-planting.

But it is a good thing to have a law, even though it is seldom enforced. For example, in France under the first Republic (twenty-eighth Ventose, year IV of the Republic—March, 1796) a law was enacted against the brown-tail moth, requiring the collection and destruction of the winter nests of the insect. This very old law still holds, but its enforcement has gone out of style. In 1910 it was suddenly enforced in the fruit-tree nursery region of Angers, largely on account of protests from the United States importers of fruit-trees. And ten years later Professor Bouvier of the French Academy advocated its enforcement in an extensive domain bequeathed to the academy and situated near Mont Morillon, Department of Vienne.

Taking everything into consideration, it seems to me that one of the great hopes for the future of agriculture is that cultivation and cropping methods will come to be controlled by a system that will make it very difficult for the insects. The system seems so simple and so natural! Just look at it concretely. The greatest, probably, of all the wheat pests in the United States, the Hessian fly, can be controlled if the wheat is planted between certain dates. The chinch-bug, another dangerous enemy to wheat, can be controlled if farmers generally can be induced to do a certain amount of cleaning up in the winter, principally by burning all the bunch-grass along the roadsides, since the insect hibernates preferably in such grass. The clover-seed midge can be controlled by a slightly earlier cutting of the first crop of clover. The cotton boll-weevil can be held in check by the use of a fast-maturing variety of cotton, sufficient fertilizing and cultivating to produce an early crop, and the cutting down and burning of the stalks well before winter. The European corn-borer, as we have shown, can be controlled by the destruction of the corn-stalks at any time during the seven months that include the winter.

And there are many such methods already known to us, and many more that will be worked out. We will mention only one that has come up within the past ten years. The so-called split-worm of tobacco, a little larva that mines the tobacco leaves in the southern Atlantic States, was studied for some time, and finally it was found that early planting, the destruction of stubble, and the cleaning up of rubbish in and around the field were the only remedies needed. Careless, "sloppy" practice had really been responsible for the increase of the pest.

An interesting discussion took place at the 1930 conference of the Imperial Bureau of Entomology in London. Mr. F. A. Stockdale mentioned a number of instances where insect pests had been satisfactorily controlled to a greater or less extent by cultural methods, and urged that entomologists should give their attention to this line of thought. His examples were taken from the relation between thrips and cacao in Grenada and the relation between shade-trees and outbreaks of thrips. He said that the shot-hole borer of tea in Ceylon had been much reduced by attention to cultivation and by the use of nitrogenous manures.

In the same discussion Dr. J. G. Myers said that the pink boll-worm on the cotton-growing islands from Nevis to the Grenadines, including Barbados, has decreased from 90 per cent to almost nothing, and that in some islands the fact has been attributed to a change in the planting season. Dr. Myers further showed that the banana weevil is almost negligible on the larger estates where clean culture is practised, but that on peasant lands it is always likely to be a real pest.

Over in England an excellent procedure has been worked out by Mr. J. G. H. Frew. The gout-fly of barley is a serious menace over there. Mr. Frew, by a very complete study of the life-history of this pest, has indicated measures that include planting and harvesting times and the use of certain manures, particularly superphosphates. By the adoption of these measures, fly-damage will become negligible. In this case as in most of the others, a decided readjustment of the farmers' plans must be made.

Sir John Russell, Director of the Rothamsted Experiment Station, in an address on present-day problems in agriculture, after referring to the interesting result of Mr. Frew's work, called attention to the work of E. A. Andrews in India, who found that tea bushes well supplied with potassic fertilizer escape attacks from the so-called mosquito-bug (Helopeltis) for the rest of the season, apparently because bushes so treated become unsuitable as food for the pest. Sir John also stated that Mr. H. H. King, in the Sudan, had effected some degree of control of the cotton thrips by giving the plant protection against the drying north wind and so maintaining a rather more humid atmosphere—a condition in which the plant flourishes more than the pest.

In fact, I think that England deserves much credit for the way in which she has devised her practices of cultivation so as to avoid in some measure large-scale insect attack. Indeed, it was the Englishman John Curtis who first recommended the planning of the sowing-time of cereals toward that end. The general subject is considered in an especial chapter by the English writer R. A. Wardle in a recent book, "The Problems of Applied Entomology." The chapter is entitled "Cultural Influence," and the general subject is considered under the subheadings "Soil Influence," "Cultural Practices," "Ground Clearing and Ground Breaking," "Manurial Practice," "Water Duty Practice," "Crop Rotation" and "Sowing Practice." It would be well if a careful study were made of the majority of our principal crops for the direct purpose of ascertaining the value of possible changes in methods. Of course this has been done by the entomologists in many cases, but the mass conservatism of the farmers has prevented the adoption of many sound ideas.

A very much more general appreciation of the possibilities of methods of this kind will follow a broad study of the ecology of a given insect pest or of a given crop. There are many ecological factors to be taken into consideration before the question as to how best to grow a crop to avoid destruction by injurious insects or disease can be settled. Sometimes, as in the case of the Hessian fly and of the clover-seed midge under the conditions that exist in the northeastern United States, it is very simple. Elsewhere it will be more complicated, but it is always the first thing that should be looked into after the life-history of the insect is well understood in a general way. The changing of agricultural methods, it is true, will usually upset what has been considered an economic practice, but it is at the worst a choice of evils, and very often the solution can be worked out.

The immediate action which one naturally takes when insects are found to be destroying his crops or other property is to try to kill the pests in the stage in which he finds them, or artificially to protect the crop against them.

Measures of this kind must always be taken in emergencies, and even while the studies are being made to find means of preventing the ravages of a given species—means based on complete knowledge of the biology and ecology of the species, which requires years in the gaining—we must take some action at once. So mechanical measures and poisons, with the machines to apply them, have been matters of study for years, high degrees of effectiveness have been reached, and improvements are being made every year. Large sums are invested in the manufacture of such machines and of such poisons, and their output is enormous and growing.

Back in the early days, when the Colorado potato-beetle began its spread to the eastward, arsenical poisons were first used, and Paris green was hit upon as a cheap and effective remedy. Ordinary white arsenic, being readily soluble in water, burned the leaves of plants, and therefore could not be used. It was soon found that Paris green in water sprayed on apple trees just after blossoming time would kill the codling-moth larvæ and thus prevent wormy apples. And then began an era of the development of spraying machines which has continued until the present day.

In the late 1870's the ravages of the cotton caterpillar caused a great extension of the use of Paris green and big horse-drawn spraying machines were invented that would under-spray the leaves of twenty rows of cotton at once. But these were found to be impractical on account of the unevenness of the surface of cotton-fields, and the spraying was done by a negro on a mule, carrying a short bar across his saddle pommel with a coarse cloth (Osnaburg) bag of Paris green tied to each end of the bar. The jogging of the mule distributed the poison dust through the meshes of the bag to the row of cotton on each side.

London purple, a waste product in the manufacture of aniline dyes which contains a somewhat variable content of arsenic, was used for a time, but when it was found that its color was very attractive to negro cooks, who wanted to use it in making ice-cream and cake frosting, it was abandoned. I am not sure that any human being was ever killed in this way, but the late W. S. Barnard saw a cook on a Mississippi River steamboat get this beautiful coloring matter from a bag of the poison stored on the deck of the steamer and intended for some cotton-planter.

The development of the machines used in spraying crops has been most interesting. From the time of the simple bucket-pump of the 1880's down to the great power sprayers of to-day, hundreds upon hundreds of machines and improvements have been patented and put on the market. The manufacture of spraying machines for orchards is now a great industry, and the machines are used also for shade-tree work and in parks. It is one of the marvelous things in applied entomology to see one of the huge government power sprayers at the side of a road in the hilly New Hampshire country, drawing its supply of water from a roadside stream and sending out through its strong sectioned hose a poisonous stream which, possibly three quarters of a mile away, at the top of a small wooded mountain, is sprayed over the tops of the trees growing on the opposite downward slope.

This mountainside spraying of forest trees probably represents the culmination of the process, in size of operation and equipment, but large-scale spraying, with expensive apparatus, will probably persist for many years in the protection of shade-trees along the streets of our cities, against the elm-leaf beetle and various caterpillars. Systematic spraying, although with smaller machines (on account of the lesser height of the trees) will still be practised in our big orchards for years to come although there is a possibility that large-scale fumigation methods may come into use; and we must not forget that very extensive orchards may perhaps be dusted economically from airplanes.

Improvements in spraying machines of different types are still being made. Only recently there were reports of improvements in the machines used for forest and roadside spraying in the regions inhabited by the gipsy-moth. Light-weight machines that can be operated in places where heavy machines could not be driven have been designed, and improvements have been made so that these machines may be operated up to one thousand pounds working pressure with hose-lines three thousand to six thousand feet in length. Moreover, improvements have been devised so that trees can be satisfactorily sprayed when the truck is moving as well as when it is stationary.

Although millions of pounds of arsenate of lead are used annually in the orchards of the United States, and although arsenic is a violent poison to man and to domestic animals, very few fatalities to either have occurred in the fifty or more years of its rapidly growing employment against insects. Nor is there any reliable evidence that it has caused the death of birds. The men engaged in spraying against the gipsy-moth in the woodlands of New England have been searching for evidence of bird-destruction through poisoning for many years, but have never reported a case. The late William Brewster of Massachusetts, an ardent ornithologist, complained bitterly at one time that the birds around his charming woodland home were disappearing, and he laid it to the poisoning. The truth is, in all probability, that after the poisoning had killed all of the leaf-eating insects the birds left because there was no more insect food for them.

Despite the success of arsenical sprays in this country and of their very general use, European horticulturists have been slow to adopt them. In England and in France especially, the advice of the entomologists has been overruled by medical opinion. In English colonies the sprays have been employed, but in the French colonies the orchardists are subject to the French laws which forbid the use of soluble arsenicals. The introduction of the Colorado potato-beetle into France following the World War, however, has brought about some change of opinion, and arsenicals are used on the potato crop.

The complaints of foreign buyers concerning the amount of arsenical residue on sprayed fruits from this country, and the rejection on this account of whole cargoes of American apples, caused a tremendous flurry among American apple-exporters in the winter of 1926–27. The rejected apples came mainly from the Northwestern States, where the long summer necessitates more than one spraying to catch the second or even a third generation of apple-worms. This serious interruption of foreign commerce opened up once more the whole question of insecticidal sprayings. No complaint has been made of apples coming from localities where only one early spraying was done shortly after the blossoms dropped; and the Western apples can be washed before shipment, although at considerable expense. But the search is on for an efficient insecticide that will be harmless to vertebrate animals. Elaborate tests with different substances are being made, but pending possible success many big packing establishments in the Northwest are introducing machines for washing the fruit.

However, it is not alone in spray form that arsenicals are used. They are mixed with attractive baits for cutworms, wireworms, grasshoppers, and other insects, and often on a large scale; always, however, with some danger to birds and to domestic animals. In Australia there has been a great outcry concerning the poisoning of the native birds by the baits that have been set out in enormous quantity in the effort to control the rabbit pest, and very likely the protest has been justified.

Again, the use of arsenicals in dust form has come in, not only in orchards but also on the large cotton plantations of the South, in the effort to control the cotton boll-weevil. This new method of using the poison has necessitated the invention and construction of different types of distributing machines, certain kinds for the orchards and other kinds for comparatively low-growing crops like cotton. Here, moreover, a different type of arsenical is called for. The arsenate of lead used in spraying orchards is too heavy to be applied in dust form, and therefore arsenate of lime has come to be employed, and the users insist upon special physical qualities, of flocculence, so that the dust will spread

Large power-operated duster for the application of dust to combat the onion thrips. (After Campbell, U. S. Dept. Agriculture.)

Treating lemon trees in southern California with hydrocyanic-acid gas. (U. S. Dept. Agriculture.)

in the air and will cover a large space—several rows of cotton, for example. Many kinds of machines have been invented and manufactured for this purpose.

Since the World War, airplanes have been steadily improved and adapted to many uses. Their availability for spreading poison dust against insects was soon recognized, and has already gone far beyond the experimental stage. Commercial airplanes contract to dust cotton-fields of the South at a moderate price per acre; airplanes are combating certain forest insects in Canada, in Poland, and in Bavaria; they have been used against grasshoppers in the Philippines, in Russia and in Mexico. Successful experiments have been carried on against worms feeding on large tomato plantations in Mexico and on large walnut groves in California. Airplane dusting with Paris green mixed with road-dust or Fuller's earth or some other diluent has been found to kill the larvæ of the malarial mosquitoes, and consequently airplanes have been employed for such distribution with success and with economy in Louisiana, Texas, Virginia, and South Carolina. This poison has also been dusted on water surfaces successfully by other methods, in Italy, South Russia, India, the Philippines, and elsewhere.

Obviously the use of the airplane in warfare against insects will increase, for a time at least, and will be found available under forest conditions or wherever very large cultures of any kind are threatened by biting species. And it is quite conceivable that contact insecticides may from time to time be applied from the air.

The use of the airplane, however, especially commercially, is bound to be limited, at least in temperate regions, by the fact that the growing season is a comparatively short one, and expensive machines like these must be employed the year around in order to make them pay. With the agricultural exploitation of the tropics, however, we may expect to see them rather constantly in use. Certain airplane companies are considering—in fact have tested—the possibility of working the same planes in the northern hemisphere in the summer and in the southern hemisphere in what is our winter. It may well be that a demand for them will develop in the larger and more progessive countries of South America.

The application of arsenicals to growing plants, however, may not be long confined to that of sprays and dusts liberated by machines. The development of poison gases carrying arsenic seems to have promise. The chemical warfare services of several nations since the World War have been experimenting with gases of different sorts, and, naturally enough, have exploited to a certain degree the possibilities of their use in the warfare against insects. Early experiments of this kind in the United States were not promising, on account of the resultant damage to vegetation.

But in the summer of 1927 I was shown in Poland an invention of the Chief of the Polish Chemical Warfare Service, Lieutenant-Colonel Woynich-Sianozecki. A powder, the chemical composition of which is not known to me, had been packed into strong cardboard cylinders, each containing, I should say, about three pints (English measure). There was a fuse at the top of each cylinder. In a demonstration at the edge of a forest, ten of these cylinders were placed on the ground about ten yards apart, and the fuses were ignited. A dense cloud of smoke arose from each one, and the contents of each cylinder burned for about ten minutes. The fumes from the whole row of cylinders joined and were wafted through the forest trees to a considerable distance. Afterward the foliage was examined and was found to carry an almost invisible whitish coating which I was told was an arsenical compound. The expert entomologists who accompanied me said that the foliage treated in this way is not injured by the fumes and that the leaf-feeding insects were always killed.

Later I saw a demonstration in a very large orchard. In this case the cylinders, attached to the end of long poles contrived for the purpose, were carried through the orchard by a row of men advancing simultaneously and separated by two or three rows of trees. The extent of orchard filled with the fumes in this way was enormous. There was no wind, but the fumes spread on all sides until many acres were invaded from the ten cylinders.

I gained the impression that, if this method of extermination is as successful as it is said to be, the expensive spraying of orchards in our country may be superseded by something of the sort.

In the early autumn of 1927 I described this experience to Dr. Paul Marchal of Paris, who told me that French army chemists had been experimenting in much the same way. He showed me photographs of a very large receptacle throwing out dense fumes. But he said that in these experiments in France there was an excess of arsenical deposit and that either the foliage was burned or the distribution of the deposit on the plants was so uneven that one could not count on its uniform action against leaf-feeding insects. It may very well be that the small size of the Polish receptacles and the method used for the distribution of the fumes in orchards have obviated the difficulties mentioned by Dr. Marchal; and of course the chemical composition of the fumes may differ. Experimental work of the same general character is being done in the United States, and, through the courtesy of the Polish Chemical Warfare Service, some of the receptacles used in Poland have been brought over.

All of the methods so far mentioned are employed against insects that have jaws and really masticate their food. There are, however, great orders that do not bite or gnaw but that suck the juices of plants, with beaks. For these insects it seems impossible to use a stomach poison. They must be killed by something that they will inhale through the breathing holes along the sides of their bodies or by something that will kill them by contact. Such insects are the plant-lice, the scale-insects, the true bugs like the well-known chinch-bug, and others.

Many substances have been used as killers of the insects of this kind, and oils have long been known to be fatal to them. When petroleum oil began to be cheap in the United States it was used by gardeners and greenhouse people to a slight extent; but petroleum, like other oils, kills foliage, and hence can be applied to plants only when highly diluted with water. But oil does not mix with water. So the old gardeners employed it sparingly. It is very strange that no one with chemical knowledge seems to have had his attention drawn to this question at an early date, but it was not until some time in the late 1870's that Professor A. J. Cook of Michigan and Mr. H. G. Hubbard of Florida (both entomologists) conceived the idea of emulsifying kerosene oil with milk or with soap in order to dilute it with water, and for years thereafter kerosene emulsion remained the standard remedy for all sucking insects.

Nicotine products have been used in greenhouses against plant-lice for years, and to-day nicotine sulphate is placed on the market in large quantities and employed extensively. Its beneficial effects have apparently been duplicated by a discovery in the study of some of the fatty acids, and cheaper results are promised.

Fumigation against scale-insects on Citrus trees under movable tents in California, with hydrocyanic-acid gas, had a tremendous development, and the use of cyanide products in insect warfare has extended out in many directions. At first the gas was liberated by the treatment of cyanide of potassium with sulphuric acid. Later, liquid cyanide was developed, and cyanide of soda came into frequent use. Still later developments have been cyanide powders for use in greenhouses, and cyanide products have been employed in house fumigation against household insects, and also in seagoing vessels.

The vapor of bisulphide of carbon in granaries and houses and in closed receptacles has been used for many years and for a time was adopted even in large warehouses. On account of the extreme inflammability of the vapor of this substance, however, the insurance companies have objected to it, and of late years an earnest effort has been made to find a non-inflammable fumigant for insects injurious to stored products, not only grains and other foods, but furs, rugs, clothing, etc. At present ethyl, isopryl, and the ethyl monochlorates seem promising. A mixture of ethyl dichloride and carbon tetrachloride also is apparently successful. This subject is still being actively investigated.

In comparatively recent years, paradichlorobenzene has been found to be very effectual against the destructive peach-tree borer, and also against other insects. Moreover, sodium fluorid is now being used against cockroaches and certain other destructive species, while sodium fluosilicate is also coming into use rather rapidly in a variety of ways and against a variety of insects.

Many people place their ultimate hope in the skilled organic chemist, and in applied entomology there is a broad field for the work of chemists. We look to them for the development of the most efficacious insecticides. In fact, it is not beyond hope that eventually some chemist will discover a cheap compound that will at the same time stimulate plant life and deter or destroy injurious insects.

The records of the United States Patent Office show every month many applications for patents both for chemical insecticides and for machines for their distribution, as well as ideas for mechanical destruction of insects. The inventive powers of the American people are being tested very seriously, and bright minds are at work in other countries.

It must not be forgotten, however, that we do not rely solely on such means. In fact, down to the present time, although many of them are in extensive use, they can be considered possibly as temporary while investigations are going on that look toward more fundamental and economical measures of insect-control based upon a more thorough knowledge of every feature of insect life.

In the meantime we are not allowing ourselves to be satisfied with fairly satisfactory chemical insecticides. We must know why they are fairly satisfactory; and a number of admirably trained men who have been studying the physiology of insects are also studying the minute and detailed action of insecticidal mixtures on insect physiology, to learn, for example, just why and how nicotine products affect sucking insects disastrously, just why and how the oily mixtures produce certain effects upon nearly all insects, and so on. A full knowledge of these matters should lead to improvements in chemical insecticides.

I think it is granted by everybody that international and interstate quarantines against human diseases are abundantly warranted. And it is almost as generally accepted that quarantines against diseases of domesticated animals are justifiable. But when the United States proposed to quarantine against plant diseases and the insect enemies of plants there came a strenuous opposition from the importers. So strong was this opposition that national legislation in favor of the movement, although formulated and proposed as early as 1899, was not finally adopted by Congress until August, 1912.

Long before this the United States had been singled out by foreign countries for adverse legislation of the sort on two occasions. In 1868 and during several years thereafter all of the European countries and many others absolutely barred all grape-vines from the United States, since the dreaded grape-vine Phylloxera is indigenous here. Again, in 1898, Germany issued an edict against American fruits on account of the San José scale, and her example was followed by virtually all of the principal countries of the world. As early as 1880, California passed a law forbidding the entry from other States or from abroad of plants or plant products liable to be infested by insects, and after the San José scale scare in the 1890's many of the States established interstate quarantines.

All of this was abundantly justified. A State or a country has a perfect right to protect itself. Indeed, it is its duty to protect its citizens.

The form taken by the law of August, 1912, was the establishment of a Federal Horticultural Board. It consisted of five members—two from the Bureau of Entomology, two from the Bureau of Plant Industry, and one from the Forest Service. This board, under the chairmanship of Dr. C. L. Marlatt, who was also Associate Chief of the Bureau of Entomology, organized and formulated a series of regulations, and from its inception, supported by Congress with good annual appropriations, did admirable work and has undoubtedly saved the United States a serious loss from accidentally imported insect pests and plant diseases. The board has from the start encountered criticism and opposition, but every fair person must recognize the fact that its decisions have always been just and that its work on the whole is deserving of all praise. It seems certain that had a man with a lesser grasp of the subject, with a lesser knowledge of world conditions in regard to crop pests, with less firmness and less tact than Dr. Marlatt, been chairman of the board, there might have been serious leaks resulting in great loss of valuable property.

In the beginning of its work the Federal Horticultural Board considered the question whether it would be possible to exclude insect pests and plant diseases by inspection and certification by experts in the country of origin. Of course inspection in such countries by experts sent from the United States would have been impossible—the diplomatic services of the different countries would not have considered the proposition for a moment—but thirty-two of the principal countries concerned in the exportation of plants to the United States were induced to provide by legislation for inspection and certification by their own experts.

A practical test of this method was continued for the first seven years of the enforcement of the Plant Quarantine Act. Unlimited importation of plants was permitted under foreign certificates, but at the ultimate destination of these shipments the plants were again examined by State inspectors before being liberated to the nursery trade or to private individuals. France and Holland developed probably the best inspection services. Nevertheless injurious insects and plant diseases were found on stock imported from even these enlightened countries between August 20, 1912, and June 1, 1919. Let us look at this statement a little more carefully. During the said period of seven years no less than 148 different kinds of injurious insects were collected on nursery stock imported from Holland and 245 different kinds on such stock coming from France. A large number of these pests had already become established in the United States, but many others were new to the country and seriously threatening to our horticulture and agriculture. Moreover, there was a large variation in the yearly efficiency of the foreign inspection services.

Further, it was found that with some pests and plant diseases no foreign inspection could possibly be perfect or anywhere near perfect. For example, no inspection would reveal the presence of the Oriental fruit-worm in certain stages of its growth, nor of the chestnut blight, nor of the Citrus canker. Still further, it transpired that even reinspection at destination in the United States could not be depended upon as a complete safeguard. Dr. Marlatt has said[1]:

> A few States were equipped with adequate authority and forces to examine imported stock at destination. Other States, however, were not so equipped, and the volume and wide distribution of the material led to a great deal of it going uninspected or receiving such superficial examination as to give no real protection.

So the results of this seven-year trial demanded a change, and Quarantine Regulation No. 37 was issued by the Secretary of Agriculture. Under this regulation the entry of most nursery stock and ornamentals was restricted to kinds that were thought necessary to the development of American horticulture. Unlimited entry of certain classes of plants was allowed, and provision was made for the entry of any other plant provided a reasonable need could be shown.

On the announcement of this regulation, trouble began. Nearly all classes of plant-importers found that their previous broad liberties were seriously interfered with. Bodies of commercial importers, individual amateur growers of plants, garden clubs, and other organizations of the kind passed resolutions, ap-

[1] "Atlantic Monthly," June, 1925.

pointed committees, and brought all sorts of pressure to bear to regain the old privileges. Boiled down to small compass, the various objections to the regulation were as follows:

(1) That its alleged protective purpose—that is, to exclude plant pests—is a subterfuge, the real object being trade protection.

(2) That it is now a practical embargo on entry of plants and will ultimately place a permanent check on the development of American horticulture.

(3) That the restrictions are not justified by the dangers of new pests, and that any risks which actually exist can be adequately safeguarded by inspection and certification in countries of origin.

(4) That it was dictated and is being autocratically administered by a few men and that it oversteps the quarantine powers authorized in the Plant Quarantine Act.

(5) That it was promulgated without warning and that a few insiders were thus able to get an advantage.

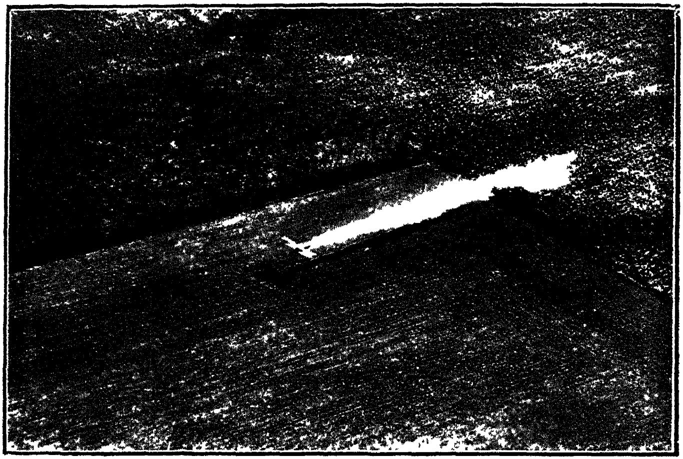
(6) That it is very likely to lead to retaliation on the part of other countries.

All of these objections were answered in the fullest and most satisfactory way by Dr. Marlatt in his "Atlantic Monthly" article already cited. It is interesting to note, regarding the charge that the real object of the regulation was trade protection, that the first and strongest wave of opposition was from commercial plant-propagators—nurserymen and florists. That it has encouraged efforts to grow nursery stock and ornamental plants more extensively in this country cannot be denied, but no thought of the protection of these interests from foreign competition entered the minds of any one connected with the issuing of the regulation. The second objection is proving entirely false. The third was made by people who did not understand the real dangers. The fourth, charging that the regulation meant dictation and administration by a few autocrats, and that it overstepped the powers authorized in the Plant Quarantine Act, is met by the fact that the Federal Horticultural Board is not only "authorized" but "directed" by Congress to issue such regulations. The fifth objection was of course perfectly unjustified. And as to the sixth, while there have been howls from abroad, there have been no serious retaliatory measures.

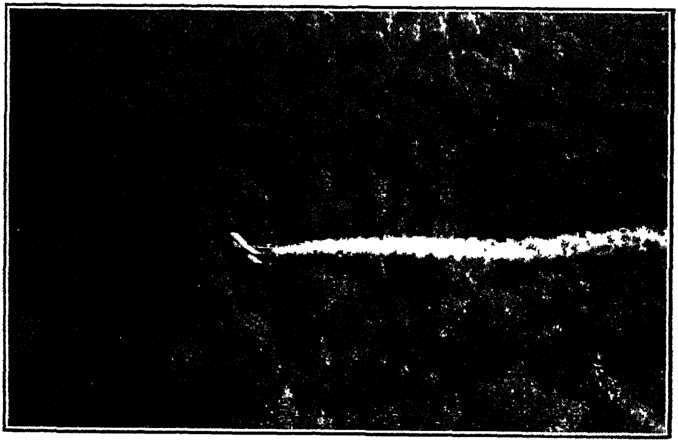
The bulb-growers have perhaps made the greatest complaints. They have sent representatives to this country from Holland. They probably instigated the call for an international conference of entomologists and phytopathologists in Holland in 1924, and certain of them have started nursery projects in this country and have grown their own bulbs and other things on a very large scale over here.

The international congress of entomologists and phytopathologists just referred to was held at Wageningen, Holland, and was largely attended. None of the Americans who were there had any connection with the Federal Horticultural Board, although there were several delegates from Washington, D. C. We were received with great courtesy and frequently entertained at large dinners in different places, and many of the speakers pointed out the iniquities of Quarantine 37 and dilated upon the care with which plants were grown in Holland and upon their absolute freedom from pests. I remember one speech in which the burgomaster of a certain town so eloquently described the woes of Holland that his eyes moistened at the pathos of his own remarks.

Before this much-objected-to regulation was issued there were public hearings and conferences following a year's discussion with State officials and nursery inspectors, and then a large public hearing was held, notice of which had been sent out two months earlier. At this public hearing, which was largely attended by interested persons, there was an almost unanimous demand for even more drastic restrictions than



Dusting a field of young cotton in Louisiana with calcium arsenate. (U. S. Dept. Agriculture.)



Dusting a swampy forest in Louisiana with calcium arsenate dust from an airplane. While in this case the dusting was done to destroy malarial mosquito larvæ in the swamp water below, it answers as a method of forest dusting against leaf-eating insects. (U. S. Dept. Agriculture.)

those that eventually took form. And then there was a further investigation by the United States Department of Agriculture for more than three months. And after the regulation was drafted, it was sent out widely to interested persons, and a second public conference was held. Even after the quarantine was promulgated it was not made effective until six months later. Could anything be fairer? And does not this long and careful consideration perfectly disprove the accusation that the quarantine was promulgated without warning and that a few insiders were thus able to profit?

It is difficult to realize the extent of the campaign of misrepresentation and propaganda that began almost at once against the quarantine. Nevertheless officials of thirty-eight States of the Union endorsed it and fourteen national and regional agricultural and horticultural associations also approved it by resolution. And to these may be added thirty-six similar State and local associations.

The campaign against the order, however, continued so bitterly that the Secretary of Agriculture called a nation-wide conference for general discussion and appraisal of the measure. This conference brought together people from all over the country and also representatives from the principal countries exporting plants to the United States. Very wisely the Secretary of Agriculture appointed an outside committee to attend the conference and report to him. This committee consisted of the Horticulturist of the University of California, the President of the University of Maryland, and the President of the American Association of Nurserymen. The outcome of the conference was a substantial endorsement of Quarantine 37.

This national quarantine work has been going on in the United States continuously and effectively. In 1928 the title of the service was changed to Plant Quarantine and Control Administration. Dr. Marlatt became Chief of the Bureau of Entomology in October, 1927, and in December, 1929, retired from the plant quarantine service. He was succeeded by Mr. Lee A. Strong, of California, an experienced and able man.

On December 19, 1930, Mr. Strong delivered an address to the convention of California fruit-growers and farmers at Los Angeles, California, "Some Facts on the Plant Quarantine Situation." In this address he answered conclusively all recent objections, many of which were inspired by the outbreak of the Mediterranean fruit-fly in Florida in the spring of 1929 and the strenuous and successful effort to wipe it out. Many totally unfounded statements were confuted. A favorite expression of the critics of the fruit-fly work had been that the quarantine was responsible for the bank failures in Florida. It is interesting to note that, by the work that was done in the early part of 1929, the State of Florida marketed nearly the normal Citrus crop in the winter of 1929-30, and the work of the service has been so successful that there are now absolutely no restrictions on the movement of Florida products on account of the Mediterranean fruit-fly.

Since the plant quarantine service was started it has grown in size and is now much more extensive and much more efficient than it was even a few years ago. Of course it is absolutely impossible to estimate at all accurately the beneficial results of the work of the service. It must be very great. As I am writing this a published statement comes to my desk that includes a list of pests intercepted on imported plants and plant products during the calendar year 1929. The list was compiled from the records of the inspectors and collaborators (State and customs officials) of the Plant Quarantine and Control Administration. For the most part the insect identifications were made by specialists of the Bureau of Entomology, and the plant-disease determinations by specialists of the Bureau of Plant Industry. Fruit-flies were frequently intercepted, and numerous other pests from all parts of the world were discovered in time.

One of the interesting paragraphs in the report lists the insects not known to occur in the United States that were intercepted August 4, 1929, on bouquets of flowers on the *Graf Zeppelin* from Germany. And there were also many interceptions of insects brought in by airplane. The pink boll-worm, for example, was captured in a cotton sample coming by air express from Mexico. And other injurious insects were caught coming in in the same way from Cuba and from Honduras. An interesting capture was a nematode that was found in hay in the tail gear of an airplane coming from Mexico. The mere list of the pests intercepted during the year covers one hundred and twenty pages of fine print, and a rough estimate gives the number of interceptions at something more than thirty-six hundred.

In that part of the quarantine work which is intended to prevent as far as possible the spread in this country of certain imported pests, such as the European corn-borer and the Japanese beetle, there have been in some places, of course, interruptions in travel that have been annoying. The examination of private automobiles that has been undergone by many thousands of people has proved especially objectionable to some—those in a hurry and others having such a feeling of self-importance that personal matters seem of more consequence than national policy, have objected very strenuously—and there have been many bitter roadside altercations and dire threats against individual inspectors, and there have been legal processes.

So far as I have heard, there have not been concrete instances that would be worth repeating here, but in the inspection of plant products from abroad things have happened from which a good story-teller could gain much material. Both pathos and humor are frequently connected with these incidents. I have been talking with Mr. E. R. Sasscer, Principal Entomologist in Charge of Foreign Plant Quarantines, and he has told me a number which I hand on here:

In the customs shed on the pier in New York a plant quarantine inspector saw some green foliage in a pile of trunks and found it to be that of potted box shrubs. He explained to the lady to whom the shrubs belonged that they must be destroyed or returned to Europe. She was greatly distressed, and finally burst into tears, sobbing out, "Please, please let me have them; I brought them from my poor husband's grave." But the inspector told her that he had no authority to pass them and that they would have to be destroyed. As he turned to speak to a customs inspector, there was an interruption: an angry man approached, demanding, "Are you the fellow who took that lady's plants?" The inspector said, "I denied their entry, but is that any of your business?" The retort was, "Yes, it is; I am her husband and I will report this to the authorities!" The inspector, who had an abundant sense of humor, replied, "How can you report it? You are dead! You are buried in France!"

Another time a vessel had just arrived from Bermuda, and a gray-haired elderly woman carried a basket of plants down the gang-plank. The inspector noted that the basket held cuttings of crotons, and he told her that the entry would not be permitted. The lady was much disturbed, and the inspector said he would empty the basket on the dock and return it to her. She replied that he might take the plants, but begged him to leave the soil in the basket for her pet cat. Of course the inspector could not do that, since the importation of soil also was forbidden; he emptied the contents of the basket and discovered, to use Mr. Sasscer's words, "that the lady had thoughtfully provided a sub-irrigation system—one not authorized by the Eighteenth Amendment."

In a package of embroidery and beads sent by a Chinese missionary to a resident of Washington, D. C., two "boards" were used as packing material. These "boards," covered with paper, were found to be made of the stems of sorghum, several of which showed the work of the corn-borer.

The corn-borer is a difficult insect to stop, and it has been discovered in many unusual forms in passengers' luggage. The same thing is true of the pink boll-worm of cotton. On account of this insect, cotton-seed and cotton-seed hulls are prohibited entry from foreign countries. But the hulls are used in Japan in the manufacture of various articles—for example, cheap baseballs for sale in the five-and-ten-cent stores. Then too, the Imperial Fireworks Company, of Yokohama, have been sending over so-called "daylight shells." They have been intercepted and found to contain, not only paper balloons in the shape of a bull, but also about half a pound of cotton-seed hulls. At Baltimore recently a box was examined that contained among other things fifty-nine small packages of cotton-seed from Brazil infested with living larvæ, pupæ, and adults of the pink boll-worm. There were also seeds of other plants, and living orchids, as well as miscellaneous objects and trinkets.

Just as with other prohibited imports, the people who wish to bring in plants resort to all sorts of devices. For example, a short, chunky

Mexican crossed the bridge at El Paso. He carried nothing, apparently. But the inspectors stopped him, and after taking off two or three layers of coats found that he was carrying fifty-two avocados in a home-made vest that had many pockets.

The orchid-collectors have vigorously complained and have often attempted to evade inspection. In August, 1930, a passenger on a train coming from Mexico declared his Mexican purchases at El Paso, but the inspector searched the man's person and found sewed inside his trousers a cloth sack that contained several live orchid plants. Then his overcoat was searched, and three more cloth sacks were found concealed in the lining, and these contained live orchid plants. Fifteen more cloth sacks containing live plants were found in the linings of some trousers and coats that he was carrying in a trunk and suitcase.

In an earlier paragraph we mentioned the attempted infringement of the Eighteenth Amendment. The plant inspectors sometimes also find prohibited drugs. To cite one such case, in a trunk belonging to an immigrant on a steamer just arriving from the Mediterranean were found some large taros, which look rather like big sweet potatoes. The inspector examined the tubers and noticed that one was much lighter than the others. He thought that perhaps there might be insects in the center which had devoured the interior, but he opened it and discovered that it had been hollowed out and a bottle containing a narcotic had been put in. Following this up, the customs inspector reëxamined the man and his baggage and brought to light a quantity of narcotics and other contraband stuff.

Chapter IX

THREE INSTANCES OF PROGRESS

IN THE preceding chapter we have considered several of the main lines along which the fight against insects is being waged, and have omitted only the to-be-taken-for-granted careful study of the life-round of the injurious species and their general ecology.

Now let us look back over fifty-five years and see the change that has come about in the United States. I think that we can do this well by selecting for contrast three of the great insect incursions that have occurred in that period and that have been rather widely separated in point of time, those of (1) the Western grasshopper, or Rocky Mountain locust, 1873–76; (2) the Mexican cotton boll-weevil, from 1894 virtually to date, and (3) the Mediterranean fruit-fly in Florida in 1929.

Beginning in 1873 and continuing with great intensity during 1874 to 1876, there were flights of a migratory grasshopper over the cultivated areas of a number of Western States, including

Kansas, Nebraska, Iowa, Texas, Oklahoma, part of Missouri, and other portions of the trans-Mississippi area.

Migratory grasshoppers had been known from time to time in that general region for many years, and there had been swarming flights that did much damage and caused considerable alarm in 1864. Other flights were recorded in following years, but in 1874 there came such enormous quantities of the insects that former experiences dwindled into insignificance. Growing crops in many of the States were devoured, farms were abandoned, the trend of settlers toward Kansas and neighboring States was stopped, and the farming population was in despair. Thousands of people were said to be starving, and relief measures were started in the East.

We quote from a few contemporary accounts. Here is one from Bismarck, North Dakota:

> On that day [July 7, 1875] a swarm made its appearance before which previous visitations sank into insignificance. The day was very warm, with hazy weather and gentle south winds. At 10 A. M. the locusts were first noticed, on the southwest bank of the Missouri River and in such quantities as to resemble heavy banks of stratus clouds. They passed over this station without intermission from 10 A. M. to 4 P. M. . . . It was almost impossible to estimate the extent and thickness of this swarm, extending from twenty feet above the ground, high into the

air, probably two hundred feet; and as far as the eye could reach to any point of the compass the air was full of the insects. At 4 P. M. they began to settle on the ground, and by nightfall the ground was covered with them.

A letter from Holden, Missouri, says:

You can form some idea of their voracity from the fact that they have eaten lint and decayed wood from the fences, and unpainted houses are gnawed all over, and they are now consuming the last year's cornstalks.

From Strasburg, Missouri, on June 16, 1875, came the following:

I do not exaggerate but state the simple truth when I say that I have been time and again over most of this [Polk] township, and I do not believe there is *one sprig* of timothy, clover, wheat or corn left standing an inch above the ground in the township; that not a bundle of oats will be cut; not a pound of hay or grass of any kind will be saved this season; vegetables of every kind have been totally destroyed, and all the fields, without a single exception, so far as I have been able to learn, are as bare of vegetation, even weeds, as newly ploughed ground—notwithstanding the fact that some farms have been planted as often as twice and three times this season—and the wild grass and weeds on the outlands in both prairie and timber have been either entirely devoured or cut down so close to the ground that cattle have been and still are starving to death by hundreds.

It was in this emergency that the United States Government was called upon to finance a thorough scientific investigation looking toward relief from injurious insects. Professor C. V. Riley, who was at the time State Entomologist of Missouri, devoted many pages in his report for 1874 and described a number of original observations that he had made upon the life-history of the injurious species in the neighboring State of Kansas. In this report he recommended that a national entomological commission should be appointed to investigate not only the Western grasshopper but also the cotton-worm and the chinch-bug. This suggestion gradually came to be looked upon with favor, and in the autumn of 1876 a conference was held at Omaha, Nebraska, called by the Governor of Minnesota and attended by the governors of those States and Territories that had been suffering and by various scientific men.

Although, as was shown later, the actual money loss through the swarming flights of the locusts had amounted to at least $200,000,000 in the years 1874–76, the Omaha conference was very modest in its estimate of the funds needed for scientific investigation. It asked Congress to appropriate $25,000 to the United States Geological Survey to pay the salaries and expenses of a commission consisting of three entomologists and two Western men to be appointed by the chief of the survey. Several bills were introduced, and in March, 1876, legislation was adopted by Congress that consisted of a clause in the bill appropriating to the Interior Department providing the sum of $18,000 to be spent by a commission of three men to investigate the insect. Please notice especially that the original recommendation was for $25,000 to be spent by a commission of five men.

The passage of this bill was not greeted with universal approval, and was criticized editorially in "The Nation," a journal supposed at that time to represent the best thought of the country.

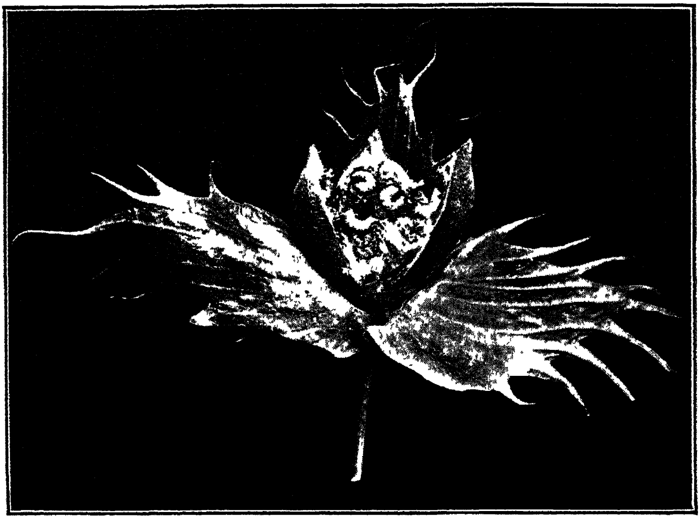
The commission appointed, consisting of C. V. Riley, A. S. Packard, Jr., and Cyrus Thomas, met and drew up a plan of action—which, however, was not acted upon by the Secretary of the Interior until March 22, 1877. (Note that a year was lost.) In 1878 the first report of the commission was published; in 1880 the second report appeared, and in 1883 the third. In the meantime seven bulletins were published by the commission, none of them relating to the locust.

Without doubt the reports of the commission were excellent. The three mentioned covered the ground admirably and form to-day a sound and well-conceived story of locust outbreaks and how to combat them, and also a consideration of the deeper questions of permanent breeding grounds and the like. Since 1876 there has been no disastrous locust swarm of widespread effect in the United States except on one occasion when a swarm settled in Otter Tail County, Minnesota, and was prompty wiped out by the energetic action of the governor and the state Entomologist, Otto Lugger. The work done by the Entomological Commission put us in good shape for all future fights of this kind, but it is comforting to think that the old permanent breeding grounds have been settled, and by settlement and cultivation their character has been so changed that there no longer exist in the confines of the United States vast areas of territory of the sort from which great locust swarms migrate in many parts of the world.

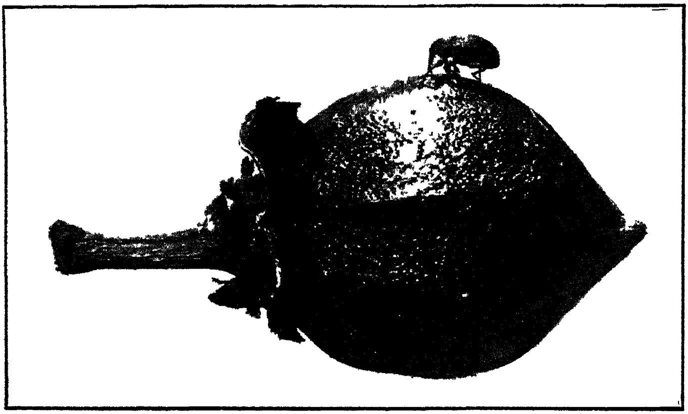
The total expenditure by the commission was small—not more than fifty thousand dollars altogether, except for the expense of publication of its reports and bulletins—but advantage was taken of the existence of the commission to further the publication of additional volumes, and a large fourth volume by Dr. Riley on the cotton-worm was issued, and an equally large fifth volume on forest insects, by Dr. Packard.

When the Mexican cotton boll-weevil made its first appearance in Texas there had been for many years no accidental entries of insect pests that caused widespread alarm or that apparently threatened serious loss to the entire country. It is true that the gipsy-moth had been discovered in Massachusetts a few years before, but that was considered to be a local outbreak covering only a few hundred square miles and confined to the eastern end of the State. It is true, also, that we had made a computation and had found out that rather more than 50 per cent of our principal insect pests had been introduced from other countries in the course of commerce. I remember, for example, how difficult it was in my boyhood to grow currants, and how we used to sprinkle currant bushes with hellebore mixture to kill off the imported currant-worm in central New York. Of course the codling-moth, which caused wormy apples almost all over the country, and the Hessian fly, which damaged the wheat crop sometimes to the extent of millions of dollars, were imported originally (probly in the eighteenth century), but they had been with us so long that they were considered standard pests to be fought as a part of orchard or farm work.

And then in 1894 we found that the cotton crop around Corpus Christi, Texas, was being



Larvæ of cotton-boll weevil as they appear in a badly damaged boll. (U. S. Dept. Agriculture.)



Cotton-boll weevil puncturing cotton-boll. (U. S. Dept. Agriculture.)

damaged by a weevil that destroyed the seeds and the lint and that had come over from Mexico, first to Brownsville and then farther north. The Government realized the potential gravity of this introduction. Agents were sent to southeast Texas, and the life-history of the insect was studied. It was quickly decided that the proper thing to do was to stop the cultivation of cotton in the infested territory—only a few counties in the toe of Texas that extends to the mouth of the Rio Grande. A bill to this effect was drafted and was submitted with the governor's approval to the State legislature of Texas, but it was defeated.

It has been contended with considerable reason that a large share of the serious damage that followed could well be laid at the door of the Texas legislature. During the autumn of 1896 there was comparatively little damage and no spread of the weevil. The preceding summer had been one of extreme drought, and it seemed to us probable that during the winter the weevil would not spread north of the growth of volunteer cotton; in other words, it would be destroyed by cold just as the cotton plant is destroyed by cold north of a certain point. This was an entirely wrong conclusion, as subsequent events soon showed. In the spring of 1897 an effort was made to find parasites of the weevil in Mexico.

In the late autumn of 1898, however, much damage had been done, and during the following winter the Texas legislature passed a bill providing for a State Entomologist; and such an official was appointed early in 1899. The Federal Government stood aside and let Texas have her way.[1]

From 1899 until 1901, therefore, the State carried on work under a duly appointed entomologist, and further offered a prize of fifty thousand dollars for the discovery of a practical remedy. At the end of this period it was found that no suggestion worthy of reward had been received, although many hundreds had been offered. And the weevil continued its spread into the most productive cotton lands of the State. In fact, it was obvious that it would surely become an interstate matter, and the people of Texas themselves appealed, through Congress, to the Federal Government.

Then began the long investigation that has lasted down to the present time. The late W. D. Hunter (a Nebraskan by birth and education) was put in charge. He studied every aspect of the cotton industry, familiarized himself with all of the possibilities in the way of cotton-culture,

[1] It has been the policy of the U. S. Bureau of Entomology to enter States only where apparently the problem affects a very large area, or when coöperation is invited by State officials.

and, with a corps of able assistants, studied every phase of the life of the boll-weevil. It was not long before he and his assistants came to the conclusion that by far the most promising attack would be by means of a variation of the current method of farming. Planters were urged to use early-maturing varieties of cotton, to plant early, to cultivate in order to hasten the crop, and then, after the bulk of the crop had been picked, to destroy the plants by burning or by burying in the ground. This recommendation was based on large-scale experimentation. Many acres of cotton were rented. Half of the area was farmed as just indicated; the rest was treated in the usual way. The contrast in the results—the vastly superior crop gained on the land farmed according to the entomologists' recommendations—showed plainly that if planters could be induced to try the new method cotton could be raised successfully in the presence of the weevil and at the same time the numbers of the insect could be very greatly reduced.

But apparently no attention was paid to the recommendations: planters continued to follow the old methods. It was said that a plantation could not be carried on economically along the proposed lines. The arranging of labor throughout the year, the difficulty of enforcing the new method upon renters, and many other things appeared to the planters to prevent even a consideration of the possibility of change.

In the meantime other matters were by no means neglected. Every possible clue was investigated ardently. The question of natural enemies received long and expert consideration—not only the natural enemies that might be supposed to exist in Mexico and Central America, but also the possibility of using the natural enemies of allied weevils—and many important biological facts were discovered; nothing, however, that would help to meet the emergency. All sorts of machines were experimented with. Some rather good ones were invented. The use of poisons in different ways was tried, but for a long time conditions seemed most unfavorable, and the weevil continued to spread. One who has never lived in the South cannot appreciate what this meant. At the time of the weevil's advent, so large a measure of the prosperity of that part of the country depended upon the cotton crop that its loss affected virtually every industry and every individual. The pest spread year after year and partial paralysis followed for a time. Mortgages on old plantations were foreclosed; negro labor fled before the weevil's advance; wealthy families were reduced to comparative poverty; banks failed; planters and speculators committed suicide.

All of these things happened, and happened repeatedly, but the spread of the weevil seemed as inexorable as fate. Louisiana made a desperate stand against its entrance from Texas, but did not gain more than a temporary delay; and after the Mississippi bottom-lands were invaded it became apparent to all thinking and far-sighted men that the situation of the cotton-belt was little short of desperate. But the mass of the planters paid small heed to the warnings and advice of the experts. Wise prophets were scouted as alarmists, and many people contended that measures should be taken when the weevil came and not before, apparently feeling that something indefinite would happen to retard or stop the spread and to save them.

It is true that at one time a delegation of prominent men from the Carolinas and Georgia visited the infested regions and the government laboratory in Louisiana and grasped the seriousness of the situation and foresaw the future disastrous results of the do-nothing policy. These men issued advice and warning to the planters of their States. But their prophetic wisdom met with no adequate response, and impoverishment, failure, and suicide marched steadily along with the weevil's progress.

It is true also that, under the urge of the Federal Government and with the support of

Congressional appropriations, a great campaign was started "to meet the emergency caused by the advent of the boll-weevil," and that strenuous efforts were made to start new agricultural industries, to vary the crop, to draw the South from its absolute dependence on a single culture. This movement, spreading gradually over the the South, laid the groundwork for the rapidly growing activities now to be seen all through that portion of the country.

Nevertheless, history repeated itself again and again. After a few years of weevil—that is to say, a few years of failure and despair—an invaded State or section of a State began to recover hope, to vary its crops and to continue to grow cotton—at an increased cost, it is true, but with the spirit of enterprise and fight that achieved once more a condition of comparative prosperity. Poor cotton lands have been abandoned; better ones have been more intelligently worked, and good crops have been grown despite the weevil.

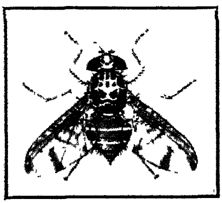
At an early date arsenic had been used with molasses as a bait with which to poison the weevils in the spring, and with some success. This process was first advocated by C. L. Marlatt. Arsenical sprays were thoroughly tested, but their general use was not recommended. In 1907 Wilmon Newell, in Louisiana, experimented with powdered arsenate of lead for the first time that an arsenical in the form of powder had been tried, and he found that it could be used successfully. B. R. Coad from this point experimented with powdered arsenicals, and from his work has come the present very large-scale use of arsenate of lime, first with ingenious horse-drawn vehicles and later (largely since 1923) with airplanes. Commercial airplane companies are now dusting large areas of cotton with success, and although the cotton-growing industry has changed in many particulars, it is now possible to grow cotton on good land very successfully in the presence of the weevil. Poor cotton land is being used for other crops. And cotton in a general way is being grown in larger continuous holdings. Cotton conditions in the South are vastly better than they were twenty-five years ago.

Looking at it in a broad way, it must be said that the boll-weevil experience has probably been a blessing in disguise—in a very terrible disguise but nevertheless a blessing. Appreciation of this fact is slowly coming. In one locality at least it was recognized a number of years ago when a statue was erected to the boll-weevil by the citizens of Enterprise, Alabama, with the legend, "In profound appreciation of the boll-weevil and what it has done as the herald of prosperity."

Here, then, is the history of a long investigation which perhaps from the old-fashioned point of view, and perhaps also from the modern point of view, has been only measurably successful. It did not stop enormous loss, but in the end it not only has placed on record a mass of discovered facts of immense value to future investigators but has helped to bring about such conditions that the United States can still produce as much cotton as before—even more if necessary.

The expense of the investigation has been considerable, but it is entirely insignificant as contrasted with the financial interests involved or with the actual money loss. For the specific work by the entomological force on this one pest, it is safe to say that about sixty-five thousand dollars a year have been spent for a period of twenty-nine years. It is true that a larger amount has been appropriated by Congress "to meet the emergency" caused by the boll-weevil, but the estimate given above includes only the amounts spent by the expert entomologists. The rest was spent largely by the Bureau of Plant Industry in various ways, one of which was to bring about a crop-variation to draw the South away from the one-crop system; another project included the effort to breed weevil-resistant strains of cotton and in the breeding work to find quickly maturing varieties; and so on.

Monument at the intersection of the principal streets of the city of Enterprise, Alabama. The inscription reads, "In profound appreciation of the boll weevil and what it has done as the herald of prosperity, this monument is erected by the citizens of Enterprise, Coffee County, Alabama." The base is 20 feet across and serves as a pool for goldfish. (Photograph by Courtesy of Prof. J. M. Robinson of the Alabama Polytechnic Institute.)



The Mediterranean fruit-fly greatly enlarged. (U. S. Dept. Agriculture.)

Larvæ of Mediterranean fruit-fly in a Florida mango. (U. S. Dept. Agriculture.)

There is a large family of flies, known as the Trypetidæ, of which many of the species are known as fruit-flies. They vary in size, but the majority of them are rather smaller than the house-fly, and they are distinctive among most of the flies in having spotted or banded wings. The members of this family are more numerous in the tropics than in temperate regions, and a large number of them lay their eggs in fruit of many different kinds. Maggots that destroy the fruits hatch from these eggs. In the more northern of the United States there are various species, but only three that damage fruit. One of these attacks apples in the Northeast and would seem to be the same species that in recent years attacked blueberries in Maine and has been the subject of an investigation by the United States Department of Agriculture. It was once thought that this species was originally an enemy of wild crab-apples, but now the idea has been advanced that originally it was a blueberry pest. Another species has been found to breed in cherries; still another in gooseberries and currants. As a rule, however, damage has never been excessive except in the case of blueberries.

In the far South of the United States, however, there are several species that attack certain fruits—one, the pawpaw; one, the fruits of different species of Ilex and Cynoxylon; another, the fruit of what is called in Florida the sparkleberry; and another, the fruit of Solanum. Then too, Trypetids have been found in the fruit of Butia, of the wild olive, and of Chionanthus. Moreover, as nuts are really fruits, it should be mentioned that there are four species that breed in the husks of walnuts.

Another and more serious fruit-fly is the so-called Mexican fruit-fly, the larva of which years ago was known as the Morelos orange fruit-worm. This insect has long been known in Mexico, but within recent years made its appearance on the Texas side of the Rio Grande, infesting grapefruit and oranges, the growing of which was assuming the proportions of a rather important industry. It thus became an inhabitant of the United States, but fortunately only for a short time. Energetic measures by the Federal Government, with the aid of the State of Texas, succeeded in wiping it out.

The other species in the United States and Canada have rather different habits; the larvæ of some of them live in galls on different plants, another one mines the leaves of parsnip, and another is found in the flower heads of various composite plants.

On account of our great interest in semitropical fruits in Florida, southern California, and more recently along the Rio Grande in Texas and to a considerable extent in the extreme south of the Gulf States, we have always been fearful of the accidental introduction of some one or more of the tropical fruit-flies. There is one species in particular, known scientifically as *Ceratitis capitata,* which though originally tropical or subtropical has been carried by commerce into various countries and has often done much damage. It has become known as the Mediterranean fruit-fly.

Although at first described from specimens supposed to have come from the East Indies, the tropical fruit-fly is altogether likely to be of African origin. It attracted serious attention in London when oranges arriving from the Azores were discovered to be badly decayed and wormy. That was in 1848. It made its appearance in Spain in 1842, in Malta about 1845, in Algeria in 1858, in Italy in 1863, in Sicily in 1878, and in Tunis in 1885. It was first reported from South Africa in 1889, and became established in western Australia in 1897, appearing in eastern Australia a year later, and in Tasmania still a year later. In 1901 it was reported from New Zealand and Brazil, and in 1904 it was found in Asiatic Turkey. Argentina reported it in 1905. Later it appeared in other parts of Africa; in 1915 in Madagascar, and in 1916 in Greece. In 1928 it was found in Hungary, infesting peaches; it had apparently been introduced from the Mediterranean region. Long prior to these later dates it made its appearance in Bermuda and eventually became a great menace to peaches there. In 1910 it was first found in Honolulu, and spread from Oahu to the other Hawaiian islands.

In 1890 the United States Department of Agriculture was notified of the damage done to peaches in Bermuda by this insect, and since that time the workers in the Bureau of Entomology have been fearing the coming of the destructive pest to the United States. The Californians had long been afraid of the Mexican orange fruit-worm and the possibilities of its introduction, and had quarantined against it. And on the discovery of the Mediterranean species in Hawaii the same State quarantined against certain Hawaiian fruits.

In 1912–13 Congress passed a special appropriation of $35,000 to make a study of the fruit-fly in Hawaii, with its immediate and primary purpose the development of means, by restriction of movement of fruits and vegetables, of preventing the fly from reaching the mainland of the United States with the products of the islands. This work was undertaken by the Bureau of Entomology and was continued by that bureau until 1928, when the reorganization of the plant quarantine work separated the research phases from the regulatory or quarantine work, turning the latter over to the newly created Plant Quarantine and Control Administration.

The proportion of this appropriation actually devoted to biological and other research studies and means of controlling the pest locally in Hawaii has averaged about $11,000 a year; for the total period (1912–30), approximately $200,000. In the latter years of this period the work on fruit-flies has been enlarged to cover work elsewhere in the United States, and, for information as to means of prevention of entry of the pest, in foreign countries also. In this way, and with the coöperation of the Federal plant quarantine service, studies were made in certain Central and South American countries, in Mexico, and in Spain. In the meantime the ports of entry in the United States were guarded under Federal and State quarantines, California having guarded her own ports against entry from Pacific countries for many years prior to the passage of the Plant Quarantine Act in 1912.

Thus the danger of importing the fruit-fly into the United States was fully realized, and strenuous efforts were being made by the Federal Government and by certain of the States for a number of years to keep it out. However, early in April, 1929, this worst of all fruit pests was found to be well established in central Florida. The discovery was made on April 6, in the region around Orlando. By that time two thirds of the fruit of that district—and in fact of the whole State of Florida—had already been moved out of the State and there was a strong chance that infested fruit had been carried into regions where it would be a very great menace.

Much of the transportation to the neighboring States of Georgia, Alabama, and possibly Mississippi had been done by means of trucks, and it was realized that a considerable amount of what had been sent out was lower-grade fruit, often what is termed "culls." This class of fruit is especially liable to be infested. There had also been shipments in bulk by rail to the more western of these States, and there had been much fruit sent out in refrigerator cars. While the probabilities were that the better part of them had already been consumed, there was still a great deal on hand in local markets and in storage far away from Florida. Therefore, the States concerned were warned immediately and were urged to make the most thorough examination of all fruit that had come to them from Florida and to destroy all that was found to be infested. They were warned also to examine the boxes that had contained Florida fruit and all of the locations where such fruit had been kept.

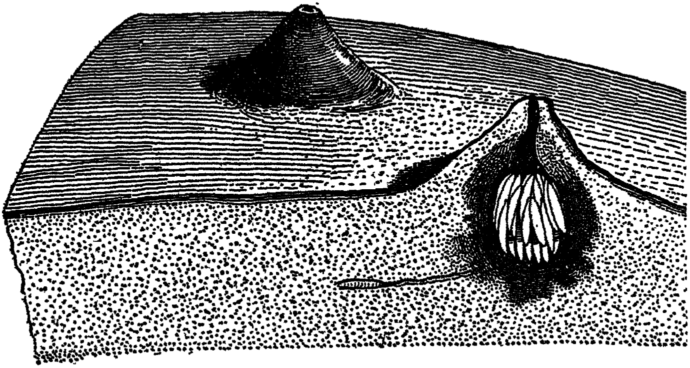
On May 15 a conference, called by the Plant Quarantine and Control Administration, was held in Atlanta, Georgia, and was attended by the quarantine officials of all the Southern States from Texas eastward. With the coöperation of the Government, all this outside work was pushed and was apparently successful. It was discovered that fourteen shipments of infested fruit, most of it in car-load lots, had been distributed to ten localities in Arkansas, Georgia, Louisiana, North Carolina, and Texas. It is interesting to note that infested fruit was reported from as far north as New York and Ohio.

In the meantime the emergency was brought to the attention of Congress, recommendations for large appropriations were made by the Secretary of Agriculture and approved by the President, and Congress promptly made available for control and eradication the sum of $4,250,000.

Under this appropriation the first step was to attempt to determine the extent of the spread of the pest in Florida, and the next was to destroy all fruits, not only in the orchards found to be infested but in all surrounding orchards. Then, after the fruit was removed, the trees were sprayed with a poison spray. All the growers concerned agreed not to ship any fruit from the groves found to be infested or from the surrounding area except under permission of the State Plant Board. A State quarantine was promulgated on April 15, covering a protective zone surrounding the infested region, and on April 25 a Federal quarantine was issued covering the whole State of Florida, effective on May 1.

Early in May it was found that the infested area was larger than at first supposed, and the Federal and State quarantines were amended from time to time to cover such extensions of territory and to provide for additional restrictions which proved to be necessary as to the movement of fruits and vegetables.

It is difficult—indeed, impossible—to decide how the pest entered Florida. All sorts of theories were advanced. The comparatively recent discovery that even delicate insects are carried alive at great elevations above the earth by windstorms suggested the idea that it might have been blown over in storms from Bermuda, and of course this is a bare possibility. It was believed by some people that bootleggers carrying loads of liquor from the West Indies to out-of-the-way points on the coast of Florida might have brought over infested fruit. It appears, however, that the forces for port inspection in Florida



Eggs of the Mediterranean fruit-fly as laid in the skin of an orange. (U. S. Dept. Agriculture.)

were inadequate, and it is the opinion of Dr. Marlatt that the entry must have been gained through the bringing into Florida by some person, either ignorantly or maliciously, of infested fruits or vegetables. Dr. Marlatt thinks that perhaps this occurred some time during the spring or summer of 1928.

It should be stated here that the Mediterranean fruit-fly has been shown to breed in almost all fruits when it is given a chance. It will apparently, however, not breed in lemons, sour limes, and nuts. Watermelons, pineapples, and strawberries have been mentioned as free from attack, but investigation has shown that the flies are especially inhabitors of trees and that therefore they do not generally fly near the ground and attack such fruits as watermelons and strawberries. They do not seem to lay their eggs in green tomatoes under ordinary garden or field conditions, and as a result these were allowed to be marketed, with restrictions, and of course any one who has been in Florida in the wintertime knows that the only tomatoes shipped are green.

The preference of the flies for trees was shown once in Spain when a number of marked flies were released from an automobile traveling along a road, and they at once flew to places where there were trees. They do not seem to attack low-growing vegetables and fruits in open, flat, sunny places in which they are customarily grown commercially. In small back yards, however, where there is plenty of shade from trees and plenty of water, they will lay their eggs in low-growing things.

In Florida the fly seemed especially fond of grapefruit and sour orange among the Citrus fruits, and was able to breed in all of them except the lemon and the sour lime. It was also found that other Florida fruits freely attacked were the guava, the Surinam cherry, peaches, and pears.

While the inspection work was going on in the other States, the Florida situation overshadowed everything else. It was necessary to stamp out the pest absolutely and in the shortest possible time.

Therefore, not only was Citrus fruit destroyed in the infested area and that immediately around it, but all fruits and vegetables ripening in the summer in the zone in its immediate vicinity were destroyed and the planting of things likely to be infested was prohibited for a time.

This was a large task. The fruit-fly was eventually found on more than 980 properties in 20 counties within the central and northern parts of the peninsular portion of Florida. The protective area included in the regulations covered 10,000,000 acres, and this included 67 per cent of the bearing Citrus trees in Florida and on a three years' average 70 per cent of the Citrus fruits normally moved from the State. However, as above indicated, the bulk of the Citrus crop had already been moved, and although thousands of boxes of Citrus fruit, over 3,000 bushels of vegetables, and 7,000 bushels of other fruit were destroyed, the actual loss to owners was not so great as it seemed, because of the earlier shipments.

There was tremendous excitement in Florida and throughout the South, and there was a vast difference of opinion among the people concerned. A bill was introduced in Congress appropriating large sums of money for partial reimbursement of growers, and estimates for the prosecution of the campaign ran into enormous sums. It is not necessary to particularize in discussing the matter now. Two committees of unbiased and acknowledged experts were sent to Florida at different times, and a Congressional committee headed by the Chairman of the Committee on Appropriations of the House of Representatives visited the State and held hearings.[2]

It was not long before certain important discoveries were made, and perhaps the most important of these was the fact that infested fruit could be sterilized either by refrigeration to 28° Fahrenheit or by heat to 110° Fahrenheit. Studies on cold storage as a safeguard against fruit-fly were conducted as early as 1906–07, especially by Lounsbury in South Africa, and from 1913–16 the Bureau carried on extensive experiments in Hawaii. With this work as a background, the research men in Florida directed efforts toward a system which would shorten the storage period. The first studies on the application of high temperatures were made by D. L. Crawford, now President of the University of Hawaii, while working in Mexico on the Mexi-

[2] In an address before the New York Farmers, December 10, 1929, Dr. Marlatt said: "I was telling the story last spring of the fruit-fly at one of the Monday evening meetings of the Cosmos Club in Washington, and at the close a somewhat sardonic doctor, a friend of mine, asked, 'Does the maggot hurt you if you eat it?' I said, 'No, it does not hurt you.' 'Then,' he said, 'why all this fuss about it?'"

can fruit-worm during 1913–14 for the Mexican Citrus Growers Association. Crawford's work and similar studies gave the basis for a very rapid development in Florida of a commercial process of high-temperature sterilization. This discovery, naturally, was the cause of very great reduction in the estimates of the amount of money that it seemed necessary to appropriate.

In the inspection and clean-up work a small army of men was employed, and many experts also were engaged, and the research undertaken by these men belonging to the Federal Bureau of Entomology was very valuable. A large force concentrated on all aspects of research connected with this outbreak, and many of the results will be of immense permanent value. As instances of concentrated research and of the rapidity with which all necessary funds were obtained from Congress, the Mediterranean fruit-fly experience in Florida stands out as the peak of work of that kind performed so far within the United States and possibly in any civilized country. Apparently the fruit-fly had been wiped out in the United States in little more than a year, whereas under old methods it would undoubtedly have become a permanent resident, would have spread, and would have caused damage that cannot be estimated.

It seems to me that the three cases we have described in this chapter have indicated better than I could have done it in any other way the growth of the knowledge of insect possibilities in the United States and the realization of the necessity for prompt action, large means, and research resources.

While the rapid settling and development of portions of the Northwest apparently removed the danger of migratory locust outbreaks affecting the midwestern States, the facts that the country was unprepared to handle large insect questions and that Congress not only delayed the appointment of a commission but cut down its suggested number from five to three and the asked-for appropriation from $25,000 to $18,000 show remarkably well the lack of appreciation that prevailed less than sixty years ago.

That Texas refused to pass a bill the result of which would have disturbed the State very little and would have wiped out the boll-weevil, and that the national Government never took action in the way of attempted extermination or quarantine, and further, that the early recommendations of the entomologists looking toward changes in crop methods were ignored, were all very discouraging facts; but that Congress finally did begin to make increasingly large specific appropriations and that intensive investigations were begun and were carried on for many years by the Federal Government—these facts indicate a tremendous change for the better.

This final episode, relating to the Mediterranean fruit-fly, brings us down to date. It shows plainly that in the United States we are awakening to the seriousness of the insect menace.

In a lecture delivered before the Maryland Academy of Sciences in April, 1930, I epitomized most of what has been told in the preceding pages, and I wrote the gist of the lecture for the pages of the journal of the academy. As I was addressing a scientific body, I tried to put it in an unsensational way, dealing with facts and reasoning logically. In order to do this I started with a series of limited and definitely stated paragraphs. I have just been reading them over, and I think that they fit in very well with these concluding words. With little modification, they were as follows:

(1) The insect type is very many millions of years older than the vertebrate type of which the human species is the latest development.

(2) The insect type has, therefore, been tried out thoroughly under world conditions, while the human species is comparatively in its merest infancy.

(3) Many forms of life have been tried, have been found wanting, and have disappeared in the course of the ages; but the insect type has persisted despite all cataclysms.

(4) The human species, notwithstanding its physical disadvantages, has jumped to the fore, with unprecedented speed, owing principally to the evolution of the quality known as intelligence. Through this intelligence it has either destroyed or controlled or converted to its own use nearly all other forms of life.

(5) The human type may be one of nature's experiments that will fail. It has not been in existence long enough to have been thoroughly tried out.

(6) In its rapid increase and spread, however, the human species has so disturbed the balance of nature as to favor the increase and spread of disease-bearing microörganisms, and to encourage enormously the multiplication and spread of injurious insects. In its efforts to feed its increasing millions, it has fed increasing millions of insects.

(7) Prophets of evil have told us until recently that human over-population of the world is approaching, and approaching rapidly; that mass starvation is sure to come; that birth-control is necessary if greater production of food cannot be stimulated or if new foods can-

not be invented. Still later prophets contradict this and tell us that scientific research has assured the future food supply even with a more or less rapidly increasing population. These optimistic people, however, have apparently assumed as a premise that the insect danger will be overcome by those working in science as applied to agriculture. The time of that accomplishment has not arrived, and it may be slow in coming.

(8) There is a third way of assisting in the feeding of the world aside from birth-control or the stimulation of plant food or the invention of new food, and that is the stopping of all waste.

(9) Probably the greatest of these wastes is the tremendous but unnecessary tribute that we pay to insects. In the United States alone the labor of one million men each year is lost through damage done by insects to crops and to our other vital interests. And this damage is increasing. The problem is very much greater than it was even twenty years ago. In order to get the quickest and most abundant food supplies, we are growing our crops in many instances in exactly the way to favor best the increase of crop pests. The cotton boll-weevil, for example, might never have been heard of as a serious crop pest if it had not been brought by accident across the Rio Grande and found itself in a great State

largely devoted to the growing of its favorite food, and growing it in just the way to favor the beetle's multiplication to the extreme. The European corn-borer, to use another example, would do little harm if we did not farm our corn lands just as we do.

(10) It is necessary that we should understand present conditions—that we should understand that insects are our dangerous rivals for the food supplies of the world, and that they are important rivals and enemies in many other ways. Then it will come about that many men will turn their attention to insect problems. Many men of sound training will study every aspect of insect life. Competent chemists, physicists, botanists, agricultural engineers, and agronomists will take the findings of the increasing number of entomologists, and upon them will base measures for the relief of humanity. The time cannot come too soon. Teachers of biology should at once begin to learn and to teach entomology.

In fact, there is here and there an advanced teacher of biology who is beginning to appreciate the importance of entomology. I have been much encouraged to read a chapter in the work entitled "The Evolution of the Invertebrates" by Professor W. C. Allee of the University of Chicago. One paragraph in the book is well worth quoting in this connection.

By most objective evidence available, size of individuals excepted, the insects of the arthropod series, rather than the mammals of the chordate series, are dominant on the earth today. They are most numerous in species and individuals. They are widespread. They practically control the great tropical regions, the most fertile of the globe; only in rare instances, as in the mosquito eradication of the Canal Zone, has man been able to hold them sufficiently in check to go about his work unharmed. In the less productive temperate regions, man is continually alert to circumvent the insects that carry disease to him and threaten to ruin his crops and destroy his food supply. In time this may become the age of man, the most highly developed mentally of the vertebrates, but at present he is only beginning to dispute the ascendancy of his rivals, the highly specialized insects crowning the arthropod series.

If I were the lucky possessor of $2,300,000, I would set aside $300,000 for my three daughters (enough for their comfortable living) and would devote $2,000,000 to the cause of applied entomology, and would provide for the expenditure of its income wholly on basic projects. And I would try to find men like the writer of the paragraph just quoted to teach the teachers of biology.

We Americans have been called eminently practical. We have also been called extravagantly wasteful. Both statements are probably correct. We focus our attention on the immediate. We seek the quickest and the cheapest remedies. We wish to stop the momentary danger, and we wish to destroy our enemies in such numbers as to reduce the loss at once. But we must not ignore fundamentals. We must search for underlying principles. In the United States an appreciation of necessary work has been forced upon us. And we are beginning to go deeper into this vital subject. Those students who are working in the newly named science of ecology, who study the relations of things, have opened up new horizons; and other young workers in England and in Germany and in certain other countries who are studying the hitherto hidden but probably simple reasons for so-called insect epidemics have a great and promising field.

The present situation is by no means desperate, but it is exceedingly bad, and will rapidly become worse if we do not give it much more serious attention. By no means do I think that the human race will go down in defeat before the insects; but it will be obliged to drag out an age-long conflict if it does not realize the danger and does not try to learn absolutely everything about every species of injurious or potentially injurious nature. It is an enormous task that we have before us, but the collective mind, once turned definitely in this direction, will undoubtedly be victorious.

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